

Canyon Creek Drainage Mass Wasting  
Inventory and Analysis

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with Roger Nichols

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#### Acknowledgements:

In 1991, Roger Nichols asked me to use my general experience in the earth sciences, and my specialties in geoarchaeology and statistics to conduct a mass wasting inventory of the South Fork Nooksack River. While this was a large increase in the scale I normally work with, I leapt at the idea, and I thank him for the opportunity. Our conversations on this, our second watershed analyzed, have been both stimulating and instructive. Gary Ketcheson has also contributed greatly to my understanding of hydrologic processes. Thanks also to Pat McCutcheon of the University of Washington for his help in simplifying the statistics used in this, and the South Fork study; one goal of these studies has been to make the statistics used understandable and useful to non-professionals. Greta Movasagghi created the slick graphs; thanks to her. Thanks finally to the Forest Service for supporting me while I tackled the effects of past forest practices.

This report has gone through several phases as the scope of the undertaking has increased with new priorities on the Forest. While much potential work remains in analyzing the trends described herein, it is hoped that those not familiar with watershed analysis and mass wasting inventories will find it of use.

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## Introduction:

In 1985, Roger Nichols, geologist for the Mt. Baker District of the Mt. Baker-Snoqualmie NF, completed a cumulative effects analysis of the Canyon Creek watershed. This study was undertaken to document the watershed's condition, and to meet the environmental quality regulations for the proposed AC-1 Timber Sale (Nichols, 1985).

Data on mass-wasting in the watershed was collected as part of that analysis in order to discuss sedimentation within the drainage. This project updates that data to discuss the mass-wasting history of the drainage, the historical and physical variables that make the area sensitive to mass-wasting, and the possible causes of slide activity in the Canyon Creek drainage. It also provides a unique opportunity to study the role of precipitation--especially rain-on-snow events--in mass wasting, for two reasons: active large scale natural mass wasting in the drainage was essentially non-existent prior to large scale human impacts. Also, the data on the physical variables of mass wasting in this relatively stable watershed is without obvious patterning, showing a remarkable evenness of distribution. Only in the historical data outlined below do we find information that correlates with mass wasting in the drainage.

The variables that appear to affect mass wasting in the Canyon Creek drainage are physical variables like soil and bedrock type, slope angle, and aspect, and historical variables like geomorphology i.e. recent glaciation, vegetation, precipitation (especially storm type, intensity, duration, and season), and the kind and scale of human impact. The distinction between physical and historical variables is in some sense arbitrary, since soil type, slope angle, and even bedrock type are products of changing historical geomorphic events. In this study, physical variables are separated from their historical contexts in so much as they respond to physical laws like gravity, or hydrostatic pore pressure changes in predictable ways, regardless of time. Historical variables, like storm cycles or human impacts (vegetation conversion), tend to be less predictable in terms of occurrence or scale. Historical variables then are the mechanisms that cause physical variables to respond in certain predictable ways to historical events.

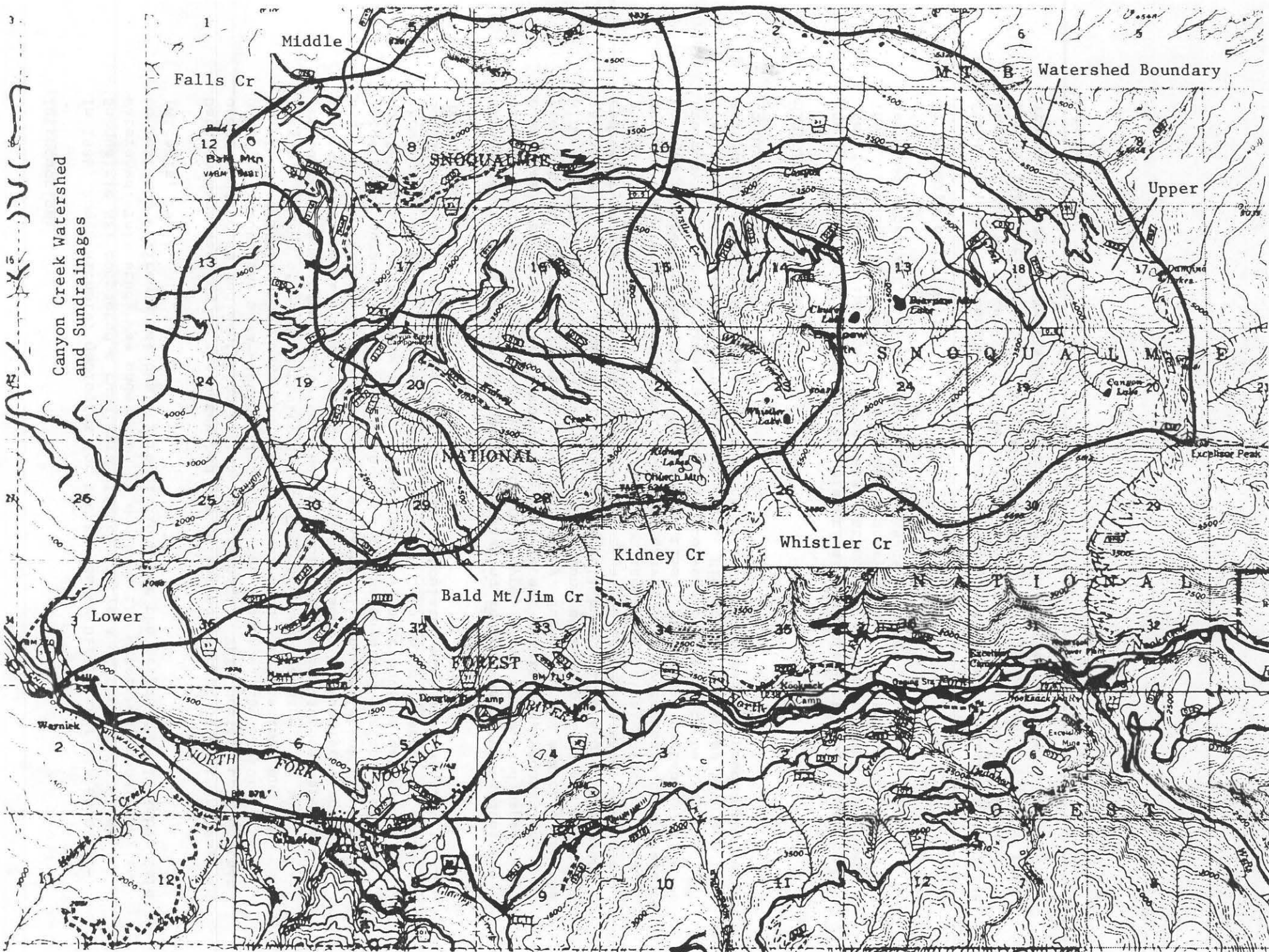
## Historical Variables:

The following section describes the historical variables that will later be used for interpreting the data on mass wasting in the Canyon Creek watershed. These include the geomorphic and human history of the watershed, and the recorded storm activity in the larger Nooksack drainage.

### 1) Geomorphic History:

The Canyon Creek watershed, is a glaciated basin, and the northernmost drainage basin in the Mt. Baker-Snoqualmie National Forest whose flow is contained within the continental United States (Figure 1). It flows west in an arc from its headwaters on the flanks of Church Mountain and Excelsior Peak, then

Canyon Creek Watershed  
and Sundry Drainages



southwest out of the Forest to its confluence with the North Fork of the Nooksack River west of Glacier, Washington. The watershed is encompassed by the Mt. Baker NE/NW quads, T40, R6/7/8, and is bounded on the south by the east/west trending Church Mountain ridge, on the east by Excelsior Peak, on the north by Canyon Ridge (that runs parallel to and approximately 1 mile from the Canadian border), and on the northwest by Bald Mountain. Elevation in the watershed ranges from 770ft near the confluence of Canyon Creek with the North Fork Nooksack, to 6315ft atop Church Mountain. Included in the study area are Canyon Creek (Class 2), and its named tributaries Jim Creek (Class 3), Kidney Creek (Class 3), Falls Creek (class 3), Whistler Creek (Classes 2 and 3), and several unnamed Class 3 streams. The geologic structure and geomorphology of the Canyon Creek drainage is complex, so the watershed is further divided by subdrainage, and into lower, middle, and upper creek subbasins. These divisions are based on changing soil types, fault zones, and slope angles.

Lower Canyon Creek flows southwesterly through an oversteepened (approaching vertical) sandstone gorge that is the namesake for the creek. Sediment in this section of the drainage tends to be noncohesive colluvium, and, excepting the large deltaic alluvial fan at the confluence of the creek with the North Fork Nooksack, less than 3ft thick. These shallow sediments/soils overlie sedimentary bedrock from the Chukanut Formation that forms bedding planes that tend to concentrate water and reduce the shear strength of the soil and sediment mass. Faulting of the sedimentary rock unit tends to be linear and perpendicular to the next order stream, forming troughs that channel surface and subsurface water. Besides oversteepening the overall gorge, glacial events in this section of Canyon Creek served to truncate many of the bedding surfaces, and undercut other areas, resulting in large block collapse. This portion of the drainage includes the private and state land that bounds the Forest, and the earliest record of logging in the drainage.

Between Lower and Middle Canyon Creek is the Bald Mountain-West Church/Jim Creek area. This area is bounded by major fault zones and changes in rock types (that include sedimentary rocks of the Chukanut Formation, slightly metamorphosed sedimentary rocks of the Chilliwack Group, and highly metamorphosed igneous materials of the Elbow Lake Formation). Recent glacial activity followed fault zones, scouring the bedrock, and leaving behind oversteepened, irregular, and unstable slopes as the ice retreated. Retreating ice also deposited recessional gravels (terraces on the upper slopes), infilling the surface irregularities (hollows), and covering fine-grained glacial deposits. Later, large gravity slides and slumps occurred as the slope angles adjusted to post-glacial conditions, and the materials were deposited on the lower oversteepened valley slopes. The resulting depressions and other slope irregularities were infilled with both coarse and fine-grained sediments weathered from local parent material, creating large areas of unstable sediment. At present this area is dominated by large scale trans-rotational failures.

Similar post-glacial geomorphic conditions exist throughout the drainage basin: glaciers scoured valley walls leaving oversteepened slopes, glacial ice melted (depositing outwash sediments on the valley floors), and mass wasting readjusted the resulting oversteepened slopes to approximate their pre-glacial

slope angles. The unconsolidated sediments were deposited in an ice-dammed lake which retreated, leaving behind oversteepened lower valley slopes, and perched outwash sediments along the valley margins and bottoms. The combination of unconsolidated sediments and oversteepened terraces creates conditions ripe for mass wasting.

In the middle and upper reaches of Canyon Creek, glaciers scoured the area to bedrock above 6200ft. The sediments deposited tend to be shallow (less than 5ft thick), and coarse-textured. These sediments are characterized by high infiltration rates and rapid permeability, and are dominated by subsurface runoff that is funneled downslope by fractures in the slightly metamorphosed sedimentary rock units of the Chilliwack Group that underlie the sediments. Below 5000ft, sediments are dominated by fine-grained silt and sand colluvium. The middle section of Canyon Creek is steep, and represents that portion where the drainage turns southwest from its westward flow. The upper reaches of Canyon Creek open up to reveal a broader valley bottom. Lacustrine deposits are evident along the valley floor to elevations between 3200ft and 3400ft, remnants of a post-glacial lake just east of the Whistler Creek confluence.

The Kidney and Whistler subdrainages are narrow, flat-bottomed channels with oversteepened headwalls. The headwall areas are dominated by snow and rock, and the channels bisect recessional gravel terraces, and glacial lake sediments. The geomorphology of both subdrainages is heavily influenced by avalanches.

## 2) Storm Patterns:

The season and duration of storms plays a critical, and perhaps dominant role as a mechanism undermining slope stability in the North Cascades. As is true for most of the region, precipitation patterns are dominated by moisture-laden Pacific air masses. These air masses cool as they move east and rise up over the mountain barrier, and the moisture condenses and falls as either rain or snow. Annual precipitation in the Canyon Creek basin is between 60 and 100 inches, many times greater than the amount that falls east of the Cascades.

Most damaging to slope stability in the North Cascades are rain-on-snow events. These winter precipitation patterns primarily affect the transitory snow zone from late October through January, the beginning season of the water year. Normal winter weather patterns are influenced by cold Arctic air masses that flow down the Fraser River Canyon in Canada, and meet with the wetter and warmer Pacific air masses blowing in from the west (resulting in snow in the upper elevations). Rain-on-snow events are the result of the unseasonal influx of Pacific warm air masses (commonly called Chinook winds), following cold Arctic air masses.

The transitory snow zone fluctuates between 1500 and 3500 feet in elevation for smaller storms, and between 1000 and 6000 feet for larger storms (where snow melt occurs at higher elevations due to increased wind speeds and temperatures). In this zone, snowpack tends to be shallow and intermittent, and the rapid melting of this snow during winter rain storms results in a higher amounts of water available than would occur with normal rainfall patterns.

The rate of snow melt and surface runoff in rain-on-snow events depends on interaction of the following: wind speed and direction, air temperature (and consequently the elevation at which snow melt occurs i.e. the freezing level), the elevation of the snow pack (the lower the snowline, the larger the area affected by warm rains and increased rapid runoff), the amount, duration, intensity, and temperature of the rainfall, snow and soil permeability, and pre-existing soil and sediment saturation levels. Unfortunately we have no physical data at this level of specificity for Canyon Creek, or even for the larger Nooksack drainage.

Upslope soils in the transitory snow zone tend to be overconsolidated saturated tills on relatively moderate slopes, in contrast to the glacio-fluvial sediments of the steep lower slopes. These tills are relatively impermeable, with limited subsurface water flow, leaving them in a state of continual saturation. They can occur within any of the till Soil Units described in the Soil Resource Inventory for the Forest (Snyder and Wade, 1970). The sudden accumulation of moisture in transitional snow zone slope sediments due to rain-on-snow events, and the rapid and concentrated increase in subsurface flow and sediment pore pressure, triggers both slope and channel mass-wasting events. Indeed, most frequent mass-wasting events occur in this transitional snow zone (as a result of rain-on-snow events), also the locus of most resource extraction impacts in the forest.

In the absence of direct rain-on-snow event data from within Canyon Creek, peak discharge information from the North Fork Nooksack near Glacier, Washington is the most accessible surrogate data (Figure 2). This information is a valid indirect source since most flood activity in the Nooksack drainage is the result of rain-on-snow events in the larger watershed (Ketcheson, 1990). Unfortunately,

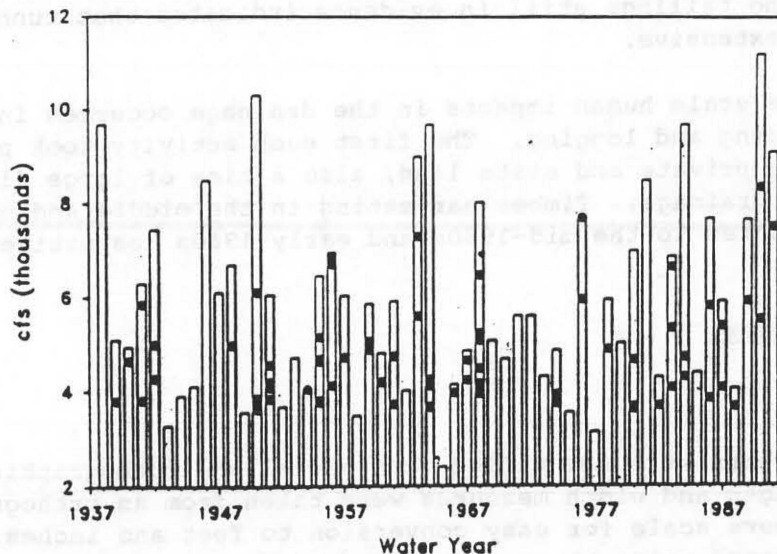


Figure 2: Peak Discharge Record for the North Fork Nooksack near Glacier, WA. Dots are secondary peaks (reprinted with permission of the author).

peak discharge information is somewhat misleading, since continuous high water discharges over time affect mass wasting in different ways than large scale, single event storms or floods.

### 3) Human History:

Human impacts in the Canyon Creek drainage were limited to small scale trail systems until the 1950s. Prehistoric people no doubt had extensive trail systems throughout the forest, and portions of this network were incorporated into historic Euroamerican trail systems. A likely candidate for this kind of adaptation is a moonshiners trail that ran along Canyon Ridge from the swamps at Sumas and Deming, then northeast where it connected with Tomyhoi Creek in Canada (Nichols, personal communication). This trail later became the route for gold miners working in the Damfino Lakes region. On a 1930 Forest Map (original base map date unknown), this trail splits off down to Canyon Lake.

The first Forest Service administrative trail can be seen on the 1926 Forest Map, the Church Mt. Trail running from Glacier, Washington, to the lookout atop of Church Mountain. A short spur ran northwest through section 29 across Jim Creek. Another administrative trail, the Excelsior Pass Trail ran from present-day Highway 542 up to the mining area at Excelsior Peak. By the time of the 1931 Forest Map, a trail ran north out of Glacier to the confluence of Canyon with Kidney Creek, up the drainage bottom, then along the eastern portion of Canyon Ridge where it connected with the Excelsior Pass Trail.

With the combined discovery of coal in the Chukanut Formation surrounding the Glacier area, and gold in the upper North Fork Nooksack basin in the early part of the century, exploration for these resources intensified in the lower reaches of the North Fork of the Nooksack basin. Coal mining was focused in lower Canyon Creek area, and gold exploration in the Church Mountain area. The amount of mining tailings still in evidence indicates that tunneling for these resources was extensive.

The first large scale human impacts in the drainage occurred in the early 1950s with road building and logging. The first such activity took place in lower Canyon Creek on private and state land, also a time of large fires in that portion of the drainage. Timber harvesting in the middle and upper reaches of the watershed dates to the mid-1950s and early 1960s respectively, and continued to the 1980s.

### Physical Variables:

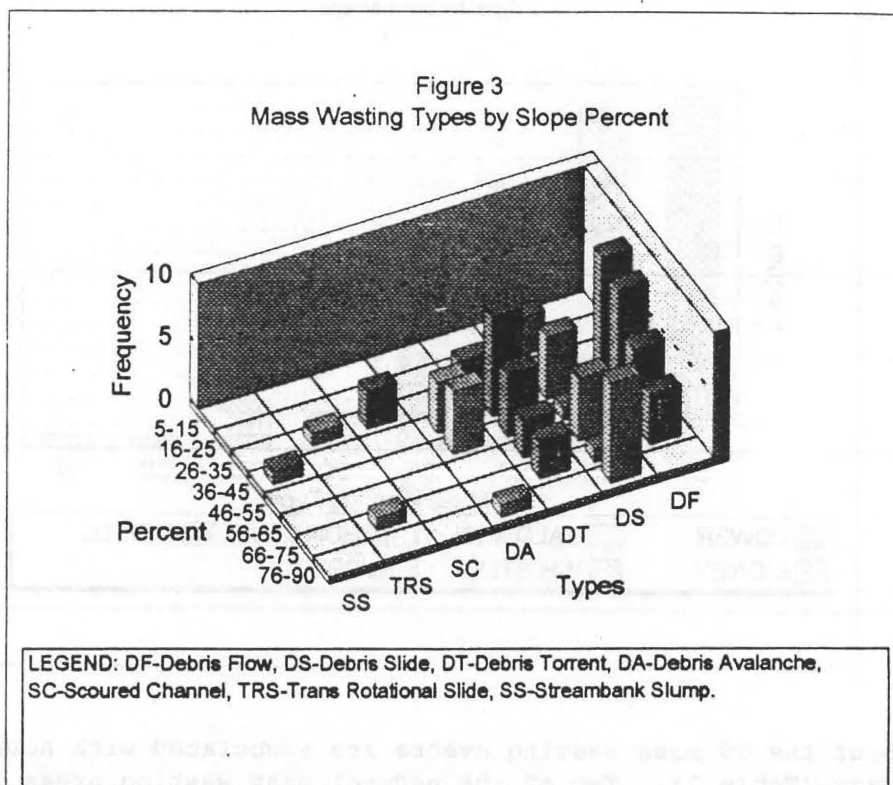
#### 1) Protocol:

Mass wasting events were identified from aerial and orthographic photos, and in the field. Length and width measures were taken from an orthographic photo using an engineers scale for easy conversion to feet and inches. The slide depth was estimated using the maximum subsurface soil depth as described for soil units in the Soil Resource Inventory (Snyder and Wade, 1970). Depth was then verified and adjusted in the field by measuring maximum depth of the slide profile with a chain. Streams were then walked to estimate the proportion of mass wasting sediment entering the next order channel.

## 2) Results of Analysis:

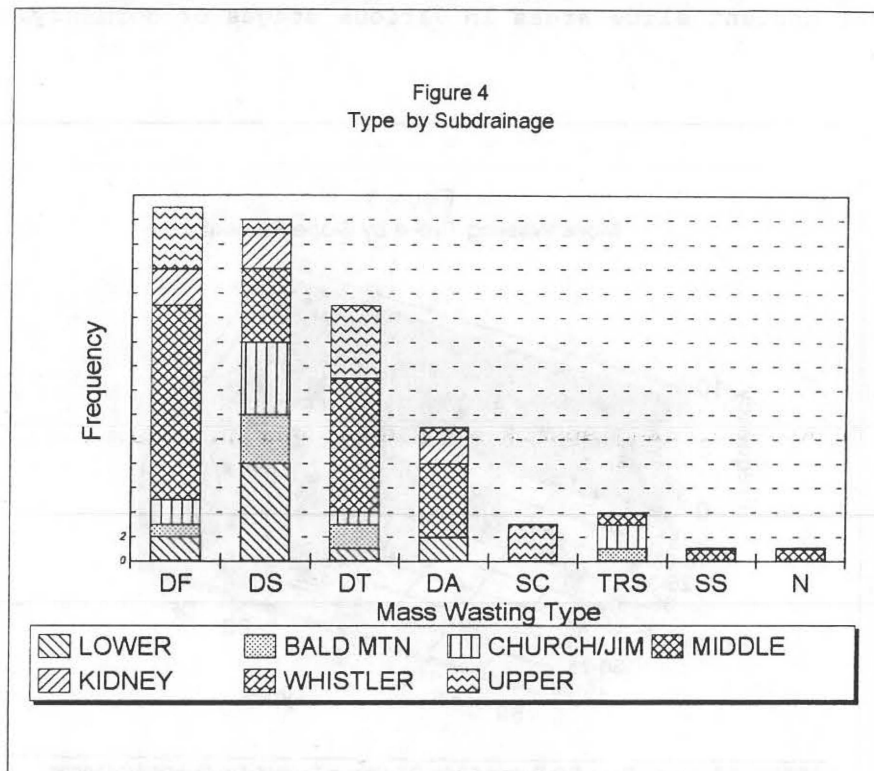
Upon casual observation of the collected data, the absence of any dominant trends within the physical variable classes is noteworthy. The exception to this is the aspect class. Within mass wasting type, slope per cent, slope position, elevation, structure, and bed rock type, data is surprisingly evenly distributed, and without significant variation. The significance of the variation evident, however, has not been statistically examined; that may be important in later phases of the study.

In the mass wasting class (total number=99), 11 are debris avalanches, 29 are debris flows, 29 are debris slides, and 21 are debris torrents. There are also 4 trans-rotational slides, and 5 that scoured perennial stream channels (plus a single streambank slump, see Figure 3 and Table 1). In addition, there are several ancient slide areas in various stages of dormancy.



Definitions of mass wasting types in the literature contain great amounts of overlap, often making comparisons between inventories difficult. Attributes used to distinguish types of mass wasting in this study were taken from the glossary of "A Cumulative Watershed Effects Strategy and Analysis Process for the Mt. Baker-Snoqualmie National Forest" draft report (1991).

Debris avalanches and debris torrents are rapid events that run the entire slope length into the next order stream, and both create narrow, linear erosional features. Debris torrents (and debris flows), however, are triggered by water. Debris torrents occur in stream beds (the result of large amounts of water that carry relatively larger amounts of debris), whereas debris avalanches form their own chutes. Debris torrents are often triggered by debris avalanches, and generally occur in intermittent channels on steep slopes. Debris flows also occur in streams but do not contain the energy of a debris torrent, so carry smaller particle sizes, and may move more slowly. Not as large as debris torrents, they do not necessarily extend the entire channel length. Trans-rotational slides involve large blocks of material that slide or rotate to a more horizontal position on the curved bedrock frame as they descend the slope. They are distinguished from the above by the size of the mass moving downslope, and by the outward movement of the mass as it descends.



All but 5 of the 99 mass wasting events are associated with human impacts in the drainage (Table 1). Two of the natural mass wasting areas in the drainage are visible on the 1940 and 1947 aerial photographs. Older slide features are visible in the areas, but the active slide areas are less than lacre in size, the cutoff for defining mass wasting events in this study. These natural events are the trans-rotational slides noted above. They are located at the major fault zones at Bald Mt. and Jim Creeks in the lower canyon. No other slide areas greater than one acre in size (that are not rock fall or talus slopes) appear on those photos. Of those mass wasting events associated with human impacts, 65 originate in clear cuts, 20 in the road prism (1 in a road cut, and the rest in road fill), and 8 in landings. The remaining 2 mass wasting events are scoured channels in the upper reaches of the creek (Figure 4).

Elevation of the mass wasting events ranges from 1420ft in the lower section of the drainage, to 4700ft in upper Kidney Creek. Slope position is the only qualitative class in the study, and differs from elevation because it is relative to the valley bottom whose elevation is declining as it moves away from the headwaters. Most slide events occurred on lower slopes (N=74; 75%), 17 on mid-slopes, and 6 on the upper slopes of the drainage (Table 4). Ninety per cent of all mass wasting events (N=86) occurred within the transitory snow zone (the locus of most human impacts in the drainage), 73% of those 86 events (N=63) on the lower slope. Of the remaining 13 mass wasting events, 12 were above the transitory snow zone, and 1 was below.

Soil data, as gathered from the Soil Resource Inventory (1970), indicates 20 soil units within the Canyon Creek watershed. Ten of these have mass wasting events originating from within them (Table 6). Toward the confluence of the creek with the North Fork Nooksack, soil units tend to be small, whereas in the middle and upper reaches, soil units are mapped as large areas covering entire Sections. With this in mind, the comparison of absolute numbers or rates of slides per soil unit is spurious without adjusting for soil unit size. Soil/sediment types in the watershed range from deep, transported, unconsolidated soils, to shallow to deep soils formed from local metamorphic, igneous, and sedimentary rock. Stability of these materials covers the range from I (most stable) to V (least stable). The predominant stability designation in soil units without slide activity is II, and in soil units with slide activity between II and IV. This is a reflection of the large size of many of the soil units that are unstable due to sediment inclusions (infilled hollows) that are prone to frequent failure. Considering the amount of mass wasting in the watershed, the sampling of the large soil units for the stability designations was not sufficient to detect these often small pockets of unstable soil contained within.

The characterization of these infilled hollows or soil "wedges" (Dietrich and Dunne, 1978), is of particular importance because it is likely that failing bedrock hollows are filled landslide scars undergoing a recurring slide event. After the initial slide event, the geomorphic history of a landslide scar includes rapid weathering of exposed bedrock, erosion of the near vertical soil banks of the scar, and possible acceleration of tree blow downs and soil creep along the margins of the scar (Dietrich, et. al., 1982). Water concentrated in the fresh landslide scar washes the fine particle sizes from material eroded into the scar, leaving behind a deposit of gravel. Sediment discharge is high during these early stages of infilling, a period estimated at approximately 100 years in the coastal mountains of Oregon (Dietrich, et. al., 1982; see also Kelsey, 1982). Other researchers have also noted high sediment discharge rates for extended periods after initial slide events (Lundgren, 1978; Tanaka, 1976). Sediment discharge decreases as the scar fills, and the filled scar may leave no topographic expression, the soil taking on the composition and texture of the surrounding soil mantle. The time estimated for infilling bedrock hollows is between 1,000 and 10,000 years, a period far too long for using aerial photos to determine recurrence intervals.

Of those soil units in which slide activity has occurred, five are tills (19, 29, 36, 37, 38), three are from the 50 series (derived from Chukanut sandstones near the mouth of the canyon in the lower reaches of the drainage), two are from

the 60 series (metasedimentary-derived soils), one is from the 70, and three are derived from extrusive igneous rocks in the 90 series (Tables 6 and 7). All the soil units excepting tills (and other transported materials) were formed in place from local parent rock. Of the 99 mass wasting events, 47 originated in transported soils/sediments, 25 are from the 50 series, 15 are from the 60 series, 1 is from the 70 series, and 6 are from the 90 series. Interestingly, soils/sediments from the 60 series cover vast areas in comparison with those of the 50 series, the differences in proportions likely due to the concentrated locations of impacts.

Table 5A: The Total Number of Mass Wasting Events, and Average Slope Percent by Aspect (for more complete data, see Table 5)

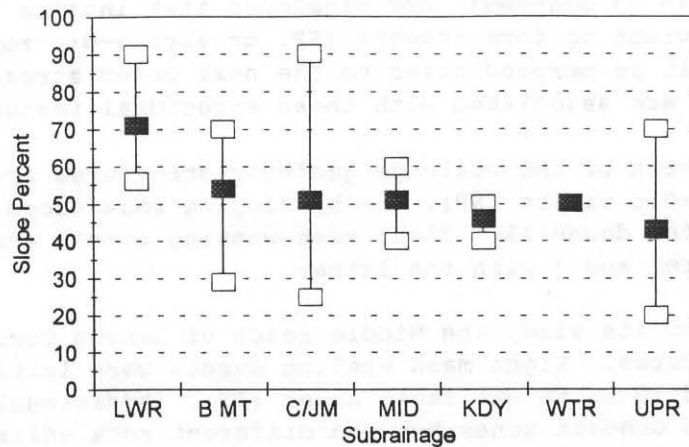
	N	NE	E	SE	S	SW	W	NW
Total Events	6	5	0	29	18	14	8	18
Average Slope Percent	57	54	0	60	46	42	46	54

Aspect (Tables 5 and 5A) is the only physical variable with an obviously skewed distribution. Eighty-seven of the mass wasting events occurred on aspects from the southeast to the northwest, 62% in the south, southeast, and southwest aspects. Only 11 events occurred in the north to east quadrant. Slope per cent (Tables 5A, 7, and Fig. 5) shows a reverse configuration, the average higher slope percents from northwest to southeast. Average slope percent in the south to west quadrant is 45%. Only the southeast and northwest aspects have both a high number of events (29 and 18), and high slope percents (60% and 54%); this may reflect impacts on opposite sides of the drainage.

When the range and average slope percent at failure locations is broken down by subdrainage (Figure 5), the dominance of aspect in the subdrainages becomes more apparent. It is likely that the high average slope percent in the lower drainage reflects the overall steepness of that watershed segment. Eight of the 13 slides were initiated on SE aspects in the lower drainage. Seven of 9 events are located on the SE aspect in the Bald Mt. subdrainage, while 8 of 10 events are from the NE to NW aspects in the Church Mt./Jim Creek subdrainage located opposite the Bald Mt. subdrainage. The middle section of the drainage shows the greatest variation in aspect, though it is clearly dominated by the SE, NW, and S aspects (15, 11, and 7 of 42 initiated slides respectively). All 7 slides in Kidney Creek are on the SW aspect, and 10 of 16 in the upper drainage are on S aspects.

The importance of the bedrock structure underlying soil/sediment in drainage systems is not always given a full accounting in mass wasting studies. The underlying bedrock in watersheds serves primarily to concentrate and funnel subsurface water downslope through networks of faults and fractures (and other weaknesses in large scale rock units), and over inclined bedrock faces (dips).

Figure 5 Range and Average Slope  
Percent by Subdrainage



Changes in slope hydrology that increase the amount of water entering troughs formed by faults and fractures tend to flush overlying soil/sediment as the channels re-size themselves to accommodate to the new hydrological regime. Since water is already concentrated along faults, it does not take much change in slope hydrology to initiate mass wasting in those places.

In areas with inclined bedrock faces, the magnitude of storms, especially in the transitional snow zone, is the primary factor in slide initiation. Following harvest activities or other disturbances, the magnitude of storm capable of initiating slide activity decreases significantly. The height of the overall water table, and the underlying bedrock or over-consolidated, saturated till determines the level of the local water table, and changes in slope hydrology can result in a sudden rise in the water table that overwhelms the saturation capacity of thin overlying soils. Valley slope soils form primarily in recessional outwash sediments or consolidated till, or on upslope parent rock. The combination of shallow, non-cohesive soils, a high water table, and steep slopes (>26 degrees) makes these soils particularly susceptible to changes in water concentration that produce intense and rapid runoff.

Rock units and geologic structures in the North Cascades are more diverse and complicated than almost anywhere else on the continent, and like the rest of the North Cascades, geologic structures in the Canyon Creek basin are complex. Accretion of numerous different rock units over time has resulted in intricate fault and fracture zones, and in varying degrees of metamorphism and uplift. This is especially true in the Bald Mt/Jim Creek sub-basin that is bounded by a series of high angle faults (greater than 35 degrees) that separate large scale rock units. Large, ancient trans-rotational slides are located in this sub-basin, with active mass wasting occurring along the headwalls. Fourteen mass

wasting events are associated with high angle faults (HF) in this sub-basin, with an average slope angle of 26 degrees, or 50%, a common slope angle for shallow, rapid failures (Table 9).

The Kidney Creek subdrainage is dominated by thrust faults (TF have slope angles less than 35 degrees), and dipslopes that incline toward the channel at an angle sufficient to form troughs (SP, or strike-dip zones where the strike of the rock unit is perpendicular to the next order stream). Seven mass wasting events are associated with these structural features.

In the Lower reach of the drainage geologic structures are dominated by trough-forming strike-dip slopes (SP), and by sloping rock faces or bedding planes (DS) that direct water downhill. Eight mass wasting events are associated with the former structure, and 4 with the latter.

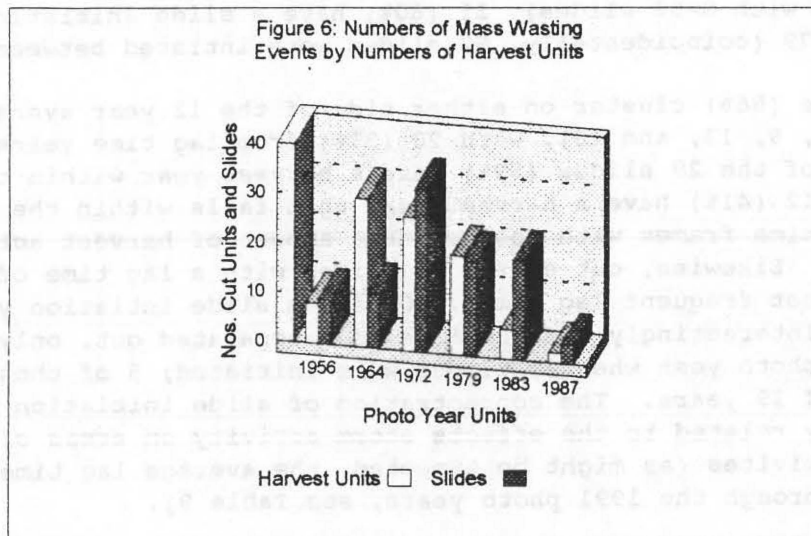
Partially due to its size, the Middle reach of Canyon Creek has a number of structural features. Eight mass wasting events were initiated in strike-dip zones (SP), and 10 in thrust fault zones (TF). Additionally, 9 events are associated with contact zones between different rock units that funnel water (out of 10 RU failures overall), and 5 with shear zone failures (SZ). Shear zones are areas of crushed parent rock, the result of fault movement.

Mass wasting events in the Upper reach of the watershed are evenly distributed among the above structures, with 6 events associated with cleavage zones. Cleavage zones occur where rock units split along a series of aligned and parallel secondary fractures forming troughs that direct water downslope.

While the relationship between complex geologic structures and mass wasting is most reliably analyzed at the scale of the subdrainage in the North Cascades, it is interesting to note several relationships between structure and other factors in the larger watershed. Out of 65 mass wasting events whose initiation points are in clearcuts, 32 (49%) are associated with either high angle faults (N=14) or strike-dip zones (N=18). There is no apparent dominance of any mass wasting type within those events from high angle faults or strike zones in clearcuts (although debris slides within strike zones are the only notable association in the larger watershed, N=11). Clearly high angle faults and strike zones should be identified, and project placement modified in accordance with the risks inherent in these geologic structures.

## Conclusions:

When the amount of slide activity in the entire drainage is plotted against cutting activity (the number of slides vs the number of harvest units without regard for differences in acreage, Figure 6) it can readily be seen that there is a dramatic rise in slide activity during the period when a steady decline in cutting activity has begun. This is especially true within the 1965 to 1972 photo year unit where the number of slides triples the number of slides initiated during the earlier photo year unit. During this period, 33 slides were initiated, compared to 9 between 1956 and 1964 (and 5 before 1956). Additionally, 19 slides were initiated between 1973 and 1979, 20 between 1980 and 1983, and 4 after 1984. It is also during the 1965 to 1972 photo year unit that harvesting in the drainage begins a steady decline. The time spans encompassed by aerial photos are discrete units so it is not possible to determine rates of failure per year (since we do not know during which years mass wasting was initiated within the photo year unit, and it is possible that slide activity within certain photo year units is the result of single large magnitude storms). To complicate matters, the time spans within photo year



units are not equivalent, making comparisons of photo year units difficult. For instance, 33 slides were initiated sometime during the 7 years encompassed in the 1972 photo year, 19 in the 6 years within the 1979 photo year, and 20 in the 3 years of the 1983 photo year. We can collapse the 1979 and 1983 photo years creating a 10 year time span (N=39 total slides), but without information on the exact year of slide initiation, it is not possible to directly compare the 10 year unit (1979 plus 1983) to the 7 year unit (1972) in terms of absolute numbers, or rates per year (assuming equal distribution of slide initiation within the years encompassed by photo years).

To clarify the relationship between cutting activity and slide activity, lag times (the difference between cut year and slide year, or how long after human impact the slide was initiated) were calculated for each slide (Table 9).

Negative lag times, where the slide year is greater than the cut year, indicate natural reactivated slide areas. Natural slides also include ancient dormant slide areas without any associated human impact (N=12 total active slides with negative lag time years and ancient dormant slides). The range of negative lag times is between negative 2 and negative 34 years.

Slide activity caused or exacerbated by human activity is indicated by positive lag times (or zero where the slide year and cut year are the same). Positive lag times are influenced by the extent of vegetation conversion due to impact, site specific physical characteristics, and storm activity. The span of positive lag time years is between zero and 35 years, with an average of 12 years.

The mode, or most common lag time between the harvest year and slide initiation year, is 8 years (N=13). In fact, lag times between 7 and 9 years account for 26% of all lag times, and lag times between 7 and 15 years (the years surrounding the average and the mode) are 44% of the total lag times. Additionally, 1 and 2 year lag times are 11% of the total. Of special note, when those lag time years with greater than 4 records are separated out (8 lag time years with N=52 slides), 31 (60%) have a slide initiation year of either 1972 or 1979 (coincidentally, 52 slides were initiated between 1972 and 1979).

Twenty nine (56%) cluster on either side of the 12 year average (from lag time years 7, 8, 9, 13, and 15), with 20 (39%) from lag time years 7, 8, and 9. Seventeen of the 29 slides (59%) have a harvest year within the 1956-1964 photo year, and 12 (41%) have a harvest year that falls within the 1965-1972 photo year, the time frames with the greatest amount of harvest activity in the watershed. Likewise, out of the 13 slides with a lag time of 8 years (the mode, or most frequent lag time), 10 have a slide initiation year of either 1972 or 1979. Interestingly, of the 52 slides separated out, only 7 are from the 1980-1983 photo year when 20 slides were initiated; 5 of those slides have a lag time of 19 years. The concentration of slide initiation during these years is directly related to the effects storm activity on areas of large scale harvest activities (as might be expected, the average lag time increases from the 1940 through the 1991 photo years, see Table 9).

Since none of the other physical variables like soil/sediment type, slope percent or position, or elevation is particularly common to the mass wasting sites in the drainage (save the relationship between those variables and areas of concentrated human impact), we are left with historical variables like precipitation cycles and the scale of human impact to explain the initiation of mass wasting in a relatively stable drainage (aspect, the single physical variable exhibiting strong patterning, is explained as the result of differential storm intensity in the drainage--see below for further discussion). Specifically, the difference between the pre and post-large scale human impacted watershed lies in the alteration and reduction of the multi-layered canopy structure, and its ameliorating affect on precipitation on the surface, and especially on rates of runoff. If there is nothing anomolous about precipitation patterns since large scale impact began in Canyon Creek, then the destabilizing role of reduced ground cover assumes greater prominence in explaining lag times (since the scale of impact will be the only thing to

Table 17: Lag Times Between the Harvest Year and Year of Slide Initiation  
(by Photo Year Unit regardless of actual slide date; 1956 is the first photo year with management activity)

Slide Year	Cut Year	Lag Time	Slide Year	Cut Year	Lag Time	Slide Year	Cut Year	Lag Time
40	73	-33	72	51	21	79	51	28
40	74	-34	72	54	18	79	54	25
40	0	NA	72	56	16	79	57	22
40	0	NA	72	56	16	79	57	22
			72	57	15	79	59	20
56	53	3	72	59	13	79	62	17
56	54	2	72	59	13	79	62	17
56	54	2	72	59	13	79	64	15
56	54	2	72	60	12	79	64	15
56	56	0	72	62	10	79	64	15
56	56	0	72	62	10	79	65	14
56	56	0	72	62	10	79	66	13
56	56	0	72	62	10	79	66	13
56	56	0	72	63	9	79	66	13
56	0	NA	72	63	9	79	71	8
			72	63	9	79	71	8
64	51	13	72	63	9	79	71	8
64	52	12	72	64	8	79	71	8
64	54	10	72	64	8	79	71	8
64	56	8	72	64	8	79	73	6
64	56	8	72	64	8			
64	56	8	72	64	8	86	0	NA
64	57	7	72	64	8	86	56	30
64	59	5	72	64	8	86	57	29
64	66	-2	72	64	8	86	57	29
64	0	NA	72	64	8	86	57	29
64	0	NA	72	65	7	86	58	28
			72	65	7	86	59	27
			72	65	7	86	64	22
			72	65	7	86	64	22
			72	65	7	86	65	21
Positive Lag Year			72	65	7	86	67	19
Summary Statistics:			72	66	6	86	67	19
			72	70	2	86	67	19
Total Range: 0-35yrs			72	71	1	86	67	19
Total Mean: 12 yrs						86	73	13
Total Mode: 8yrs						86	74	12
						86	79	7
1940 Mean: -33.50yrs						86	83	4
1956 Mean: 2.25yrs						86	83	4
1964 Mean: 8.89yrs						86	83	4
1972 Mean: 9.29yrs						86	83	4
1979 Mean: 14.84yrs								
1986 Mean: 18.00yrs						91	0	NA
1991 Mean: 35.00yrs						91	56	35
						91	56	35

have significantly changed in the watershed during that time). The size of a particular lag time then is related to the above physical variables, as well as the continuity i.e. the amount of water already in the slope hydrologic system, and magnitude of storms.

The mechanism behind lag times, especially high lag times (the 40% of slides with a lag time greater than the average of 12 years), is related to the effects of precipitation on disturbed ground, and to rain-on-snow events in particular. It is unclear at what level of precipitation mass wasting is initiated in the Canyon Creek watershed, or how to translate that into the primary and secondary peak discharge level data available to us. This is due in part to the large number of physical variables responsible for predisposing a slope to mass wasting (including air temperature, the elevation of the snow pack, snow and soil permeability, pre-existing soil/sediment saturation levels, and the amount and type of ground cover), and the difficulty and cost in obtaining measures for those site specific variables.

It is known that in drainages like the North Fork Nooksack discharge levels between 4200 and 4800 cubic feet per second (cfs) move sediment through the channel. There is no consensus, however, on how those numbers can be generally related to mass wasting in the drainage. If we assume that at a discharge level of 4800cfs mass wasting can be initiated in the Canyon Creek drainage, it is possible to relate historical discharge data to mass wasting photo dates in the watershed. There is at least one primary or secondary peak discharge level above 4800cfs, above the total average discharge level of 5436cfs, or even above 7000cfs (each presumably a single rain-on-snow storm event) within each photo year unit that could be used to infer that large storm events cause mass wasting (although it is unclear at what time within the photo year unit slides occurred i.e. how many of the 33 slides that were initiated between 1964 and 1972 occurred after the 8020cfs peak discharge storm of 1968). This approach is simplistic, however, especially in consideration of predisposing factors like snow and soil permeability, and pre-existing soil/sediment saturation levels. These variables are affected as much by continuous low levels of precipitation as much as they are by single large storm events, and mass wasting may occur as a result of concentrated water routing caused by continuous low level storms, with or without the occurrence of large storm events.

A cursory look at the primary and secondary peak discharge data for the North Fork Nooksack at Glacier, Washington suggests that the 1980s were a time of large storms, and the preceding decade a time of smaller storms. There also appear to be relatively large magnitude storms approximately every ten years. If we look at this data not as isolated peak water flow events, and concentrate on the continuous peak discharge data in terms of average peak discharge, and variation within the data for each photo year unit, a different picture emerges.

The question asked of the data is no longer whether there is a peak storm event at some level that may have caused mass wasting, but whether there is a significant difference in the amount of peak water flow within and between photo year units? In other words, are there cycles of storms, periods covered by aerial photos that are notably wetter or drier than other periods, or are the cycles seen in the graphing of discharge i.e. 1965-1975, and 1981-1991 only apparent? This information is critical to explaining the preponderance of mass

wasting events that occurred between 1965 and 1972, apparently a period of low level storm activity. A corollary question then, is the period between 1981 and 1991 anomolous in the amount of peak water discharged (as it appears on the graphed data), or do the large storm events mask the overall amount of water discharged?

Two simple statistical tests were run on the primary and secondary peak discharge data (see Appendix 1 for a complete discussion). The first, the chi-square test, compares the average peak discharge data for each photo year unit (the sample unit) to the average expected discharge (the population unit). By comparing the actual average or mean peak discharge with the calculated expected average, the chi-square test helps to determine whether the gathered data is evenly or non-randomly distributed across the discharge data (does the sample drawn reflect the larger population), or whether the same data is randomly and unevenly distributed, and is a fluke of this particular sample i.e. if you drew repeated samples from the same population you would usually get numbers very different than those of our sample.

The t-test then allows us to determine which pairs of photo year units are statistically equal or unequal (whether the differences in the average peak discharge between two photo year units is statistically significant, or so small as to be considered the same i.e. that one photo year unit is generally no wetter or drier than any other). This can be very revealing when comparing a period of time that appears to have low peak discharge rates relative to other, presumably wetter time periods i.e. 1964-1972 when 33 of the 99 total slides were initiated. If the two time periods are not significantly different, then the role of precipitation as a trigger for mass wasting takes on another dimension.

Consider: the peak discharge data is the result of the largest storms of the given year (and therefore the most potentially damaging). If we conclude that the overall discharge rates between time periods is not dissimilar, four interconnected possibilities arise to explain the initiation of mass wasting, especially in the 1964 to 1972 time period: 1) the magnitude of storm that can trigger mass wasting with inordinately rapid runoff is low; 2) low magnitude continuous storm activity can act as a trigger mechanism by slowly saturating impacted (and now less stable) sediments, weakening the soil mass; 3) changes in management harvesting and road building strategies have destabilized slopes beyond their ability to absorb normal precipitation levels; and 4) the large scale cumulative effects of harvest unit sizes and locations, and the locations, construction design, maintenance, and length of roads have become noticeable.

The statistical conclusions that result from applying the chi-square and t-tests to the peak discharge data are that all the average discharge rates are non-random (not evenly distributed when compared to our expected averages), and that all the photo year units are non-random (they all depart from the expected equal distribution). Since the t-test does not indicate that the unevenness is between photo year units (that the averages and variances of the photo year units is not significantly different), the non-randomness must lie within each photo year unit. This suggests that there are important short term

precipitation cycles in the North Fork Nooksack drainage that occur within the time periods contained within each photo year, approximately 6 year intervals.

Dissecting these cycles further using photo year units and peak discharge data is problematic for two reasons: the photo year units do not contain equivalent numbers of years (which was not an impediment to the use of chi-square or t-tests, but would hinder more sensitive measures). Also, continuous discharge data (and not just peak events) would be important for further clarification of these small scale precipitation cycles. The relationship of these small scale precipitation cycles to the initiation of mass wasting, however, is beyond the scope of this study.

No attempt was made to separate rain-on-snow storms (those occurring from October through January) from storms occurring at other times of the year in the data. Twenty-seven of the ninety-nine peaks or secondary peaks from the discharge data are from other than rain-on-snow storms. Elimination of these storm discharges from the data might be revealing in our understanding of the small scale cycles of precipitation, but with roughly 75% of all peaks occurring between October and January, we can still safely assert that rain-on-snow storms account for the majority of peak discharges.

Another pattern that qualitatively supports the role of storm activity as a trigger for mass wasting emerges when we look at the distribution of mass wasting events in terms of location and aspect, and the effects of storm direction and intensity up the Canyon Creek drainage (Figure 7). Storms, especially winter storms, approach the drainage from the southwest where they enter the steep lower canyon that runs southwest/northeast. Some storm intensity is deflected up the Bald Mt. drainage that runs roughly north and south off the lower canyon before the creek makes a sharp turn toward the east into the less steep mid-canyon. Storms continue to slow and lose intensity as they spread into the relatively broad and flat upper canyon to rise up and over the surrounding mountains.

With this pattern in mind, the distribution of mass wasting sites should cluster in a number of ways. First, due to the rotational nature of storm systems, storm intensity is greatest on the outside of the curve (greater speed in relation to the inside of a curve), we would expect clusters of slides along the most northerly or westerly side of the main drainage. This is especially true at the mouth of the canyon, since storms are portions of larger air masses that move counterclockwise (anticyclones) such that a storm's greatest intensity would be along the western side of the drainage. Such is the case. Of those mass wasting events not associated with subdrainages, there is one cluster on the west slope of the lower canyon southwest of the Bald Mt. drainage, and another along the west slope of the main drainage northeast of the Bald Mt. drainage. A third cluster is evident where the channel makes its turn toward the east in the middle canyon northeast of Kidney Creek. Although not clustered, the remaining scattered mass wasting sites in the middle and upper reaches of the drainage are located on the northern slope, exclusively so where the valley widens toward the headwaters. This may be an artifact of the greater number of cutting units along the northern slope of the valley, since storm intensity should be more even in the upper reaches of the drainage.

Mass wasting in the Bald Mt. and Jim Creek subdrainages may have more to do with fault zones than storm intensity, since large scale mass wasting is noted along the headwall that borders fault zones in both subdrainages. In Kidney Creek and the other unnamed subdrainages that bisect the eastern slope of the valley in the lower and lower mid-canyon, mass wasting sites are clustered on the northernmost slopes where storm intensity is greatest. In the upper canyon, most mass wasting is associated with the portion of small subdrainages contained in cutting units.

As noted earlier, excepting the large trans-rotational slides associated with major fault zones in the Bald Mt./Jim Creek area (that were evident but largely inactive in the pre-human impact aerial photos), mass wasting in the Canyon Creek watershed originated in areas of large scale human impact. Mass wasting is not associated in any significant way with the surface variables like soil/sediment type at the mass wasting site, elevation, or slope position and percent. The structure of the underlying bedrock in the watershed (that is directly related to bedrock type) functions to funnel subsurface water downslope through faults and fractures, regardless of the overlying soil type, and determines and limits the water table. Elevation and slope position and percent are artifacts of the locations of human impact, and change over time as management strategies move upslope, and into the major subdrainages. Aspect is directly related to differential storm intensity as storms move up the channel and over the associated landforms.

A final relationship between physical variables needs further clarification. Of the 99 mass wasting sites, 52 have harvest units situated above the unit from which slide activity was initiated. As outlined in the geomorphic description of the watershed, lower slopes tend to have oversteepened margins. These slopes have not fully returned to their pre-glacial slope angles, and are very sensitive to the destabilizing effects of canopy and ground cover removal, and concentrated water routing from above. The addition of water to lower slopes from activities upslope increases their instability, resulting in greater potential for mass wasting. As with the distribution of other physical variables across mass wasting sites, there is no particular pattern of associated upslope and slide unit soil/sediment types (save the expected absence of deep transported soils in mid to upslope positions).

The role of ground cover is an important variable in predicting the potential for mass wasting in a given area. Layers of ground cover, from the surface litter to the upper canopy, ameliorate the effects of precipitation on the rate of surface and subsurface water flow in ways that cannot be overestimated. The forest canopy captures vast amounts of precipitation. Some of that precipitation evaporates or sublimates directly back into the atmosphere, and the remainder is allowed to enter the soil reservoir much more slowly than if there were no canopy. Living root systems act to hold soil and sediment in place by anchoring the soil mass to bedrock, and by strengthening weak soil masses. Deteriorating root systems from dead or cut trees may weaken soil stability over time, accounting for lag times between cut years and slide years in the data (except where geologic structures dominate, and sudden failure of the entire unconsolidated lithologic and biomass occurs with a change in slope

hydrology). The surface litter acts like a sponge, reducing the rate at which water enters the soil reservoir. It also acts as a buffer to the impact of raindrops on the sediment surface, helping to reduce the rate of surface erosion. Early succession plants can have the same effect. A plant community's ability to stabilize slopes increases as the size of plant and the amount of ground protected increases.

The importance of altered ground cover and canopy structure, and its relationship to mass wasting potentials has to do with the resilience of harvested basins in responding to normal storm activity. Over-harvested areas are at maximum stress and have no resilience in responding to storm activity. Small storms have a greater effect in harvested basins than in unimpacted basins, and catastrophic storms have exponential effects as concentrated water flows flush sediment from unstable slopes. The result is seen in increased changes in channel morphology, and in an increase in the frequency of mass wasting events.

For instance, 24" of snow is equivalent to between 15% and 30% moisture (the percentage increasing proceeding north on the west side of the Cascades towards the convergence zone between warm Pacific and cold Arctic fronts), or between 3.6" and 7.2" of water. In the forest canopy, and/or during times of normal diurnal temperature variation, that water enters the ground at a relatively consistent and slow rate. If that 24" of snow is in the transitional snow zone where warm winter rain storms are likely, the situation changes. Consider: a typical winter storm in the mountains drops 4" of rain in 48hrs, whereas a major storm is double that amount in the same time period. If that storm melts snow, the amount of resulting runoff increases to between 7.6" and 11.2" for the 4" storm, and between 11.6" and 15.2" for the 8" storm. This is an increase in the amount of water above the level of rainfall entering the system from between 145% and 190%.

In forested areas, the depth of snow cover is not uniform, and is distributed throughout the canopy where it melts at variable rates. Only in forest clearings, clearcuts, roads, and landings is snow of consistent depth and rate of melting. It is the amount of such open areas where snow can accumulate that is the primary concern in rain-on-snow events. If large sections in a subdrainage have been harvested, vast areas become available for snow accumulation and potential rapid melting during rain-on-snow events, effectively turning the impacts of normal storms into major storm events (11.2" of water including snow in a 4" storm event vs a major 8" storm without snow).

One way of calculating the declining impacts of harvesting over time is presented in "A Cumulative Watershed Effects Strategy and Analysis Process for the Mt. Baker-Snoqualmie National Forest" (draft report, 1991). This report proposes methods for tracking the changing ability of plant communities to stabilize slopes in clear cuts, in the road prism, and in other areas where the surface litter and much of the under and overstory has been removed.

In this report, the Watershed Productive Forest is the area in a drainage capable of sustaining a primarily coniferous forest forty feet high, with at least 70% crown closure. The Vegetative Disturbance Level is calculated to

provide a percent of vegetative disturbance (the result of timber harvesting, road building, or natural mass wasting) beyond which unacceptable watershed damage occurs. Unacceptable watershed damage includes mass wasting above the normal background level, changes in peak stream flow, and channel degradation.

The Vegetative Disturbance Level considers the timing of management activities by comparing the amount of vegetatively disturbed acres to the overall acres of Watershed Productive Forest. The Vegetative Disturbance Level acts as a surrogate for other variables important in determining the overall health of watersheds, much like indicator species illustrate the overall health of ecosystems. Since the Vegetative Disturbance Level includes the regeneration rates of plant communities in disturbed areas, the percentage must be updated yearly.

For the overall physiography of the North Cascades included in the Mt. Baker District, a 12% Vegetative Level has been considered the upper limit of disturbance (see Nichols, 1986). It is thought that beyond that percentage unacceptable watershed damage occurs. This disturbance level is commonly used by several Forests in Region 5 in cumulative effects studies, and has been attributed to the work of Dennis Harr, a Forest Service research hydrologist (Harr, 1987). His work involved studying changes in the size of peak flows (and the resulting change in sediment movement) when compared to the amount of compaction in watersheds from road building and logging activities that disturb soil and sediment. Harr's work was modified for the cumulative effects study for the AC-1 Timber Sale (Nichols, 1986). Harr cites three factors that can be used to describe a specific watershed's signature, factors that can be useful in assessing how forest management practices might affect slope hydrology (Harr, 1986). These factors include changes in landslide activity, channel morphology, and riparian zones. Studies like this can do much to help refine threshold limits by examining the results of past forest practices on the above factors, and by correlating changes in vegetation structures with other important variables.

Harr lists several problems in the use of the 12% threshold number (Harr, 1986). The most important is that the relationship between peak stream flow and forest management practices is continuous and without a natural break; there is no point at which watershed damage levels off with specified amounts and kinds of activity. The designation of a 12% disturbance level as an acceptable limit of activity across a region is entirely arbitrary. Some watersheds will sustain unacceptable damage at a 5% threshold level, and others may easily tolerate threshold levels much higher than 12%. It is interesting to note that, according to Harr's work, a 12% compaction level corresponds to a 32% increase in the size of peak flows.

Two conclusions can be drawn from Harr's criticisms. The first is that the determination of acceptable damage to watershed resources as the result of forest practices is a management decision. The second is that the use of any threshold level is dependent on the history and physical characteristics of individual watersheds. As shown below, threshold levels require revision as the scale of analysis becomes smaller.

In an analysis of the Canyon Creek watershed (including private land) in 1989, the Vegetative Disturbance Level for the total basin was 12.2%. In the sub-basins percentages ranged between 4.8% in the Canyon Lake sub-basin at the headwaters, and 18% in the lower canyon.

The breakdown of Vegetative Disturbance Levels by sub-basin reveals one of the problems in interpreting the percentage for entire watersheds. Analysis at the watershed scale emphasizes the timing of activities. The timing of management activities, however, cannot be considered separately from the spacing of impacts in a drainage in assessing potential watershed damage. In 1989, the total Canyon Creek basin Vegetative Disturbance Level was 12.2%, and the watershed was at its determined upper limit. If no new timber was cut, or roads built, we would consider the previous timing of activities acceptable in terms of retaining the stability of the watershed. Considering the amount of mass wasting and channel degradation in the watershed, the total basin Vegetative Disturbance Level is misleading, due in part to the large scale (where the effects of storm activity are evened-out), and also because the amount of canopy in an area is only one indicator of the potential for mass wasting.

When the 1989 percentage is broken down by sub-basin, the Lower reach (18%), Kidney Creek (12.3%), and Whistler Creek (17.4%) sub-basins still have Vegetative Disturbance Levels above the acceptable level, more than half a decade after the last harvesting in the drainage. The other sub-basins had 9.1% (Upper canyon), 4.8% (Canyon Lake), and 11.2% (Middle reach) Vegetative Disturbance Levels. At an even smaller scale, the Bald Mt./Jim Creek portion of the Lower reach sub-basin has a Vegetative Disturbance Level of 18.4%, and the still smaller Falls Creek portion of the Middle reach sub-basin a level of 19.4%. The smaller the scale, the more the effects of the spatial arrangement of management activities become apparent.

To assess how the spatial arrangement of harvesting affects subdrainages over time (and consequently the potential for mass wasting due to vegetation conversion for each photo year unit), the Vegetative Disturbance Level can be back-calculated from the time of harvest to each photo year. Such calculations demonstrate the percent of vegetative disturbance at each photo year, and help to explain the number of mass wasting events due to harvesting within the photo year units. Tables 11 through 16 list the Cut Years, Harvested Acres, and the Adjusted Acres (due to regeneration of vegetation after the cut date) per photo year for different reaches of Canyon Creek, and for its subdrainages. The Vegetative Disturbance Level for each photo year is then calculated by dividing the Adjusted Acres by the Total Productive Forest Acres (see also Table 10 below for a summary that includes mass wasting frequencies).

With similar Total Productive Forest Acres, Kidney and Falls Creeks are useful for illustrating the changes in Vegetative Disturbance Levels with changes in harvest activity. By the 1964 photo year, the Vegetative Disturbance Level for the Kidney Creek subdrainage was one percentage point (11%) below the determined maximum disturbance level of 12%, whereas the Falls Creek subdrainage was still well below that threshold at 4%. In 1972 the Vegetative Disturbance Level for both subdrainages more than doubled the 12% threshold

(29% for Falls Creek, and 25% for Kidney Creek). In 1993, the Kidney Creek subdrainage fell below the 12% threshold at 11% (a decade after the last harvest), while the Falls Creek subdrainage is still well above at 16% (seven years after the last harvesting).

Table 10: Vegetative Disturbance Levels for Canyon Creek  
Subdrainages by Photo and Current Year (for more complete data see Tables 10 through 15)

		1956	1964	1972	1983	1991	1993
Total Adjusted Acres by Photo and Current Year	Kidney Cr	---	158	347	257	176	150
	Falls Cr	3	39	308	212	194	171
	Bald Mt/Jim Cr	218	593	478	457	261	217
	Middle	214	853	907	792	420	344
	Upper	---	369	518	414	355	310
	Whistler Cr	---	64	136	148	126	116
Vegetative Disturbance Level (%)	Kidney Cr	---	11	25	19	13	11
	Falls Cr	0.3	4	29	20	18	16
	Bald Mt/Jim Cr	8	22	18	17	10	8
	Middle	12	50	52	46	24	20
	Upper	---	8	9	3	0	0
	Whistler Cr	---	14	15	16	14	13
Mass Wasting Frequencies	Kidney Cr						
	Falls Cr						
	Bald Mt/Jim Cr	1	1	3	13	1	0
	Middle	1	6	14	15	2	0
	Upper	---	2	9	3	0	0
	Whistler Cr	---	0	0	1	0	0

Since there has been only one unit harvested after the 1983 photo year (15 acres in the Falls Creek subdrainage in 1986), the decrease in Vegetative Disturbance Levels in the subdrainages since 1983 is solely due to regeneration of the plant communities, and their increasing ability to buffer soils from the impacts of storms. Clearly, the increase in Vegetative Disturbance Levels from 11% to 25% in the Kidney Creek subdrainage, and from 4% to 29% in the Falls Creek subdrainage between the 1964 and 1972 photo years had an affect on mass wasting events during that time period, regardless of changes in the amount or intensity of storm activity.

Bald Mt/Jim Creek and the Middle reach of the main drainage better illustrate the relationship between Vegetative Disturbance Levels and the frequency of mass wasting. Both areas had large harvest acreages early in the history of logging in the drainage, and both sustained high levels of cutting throughout that history. By 1964, Vegetative Disturbance Levels had reached 22% in Bald Mt/Jim Cr., and 50% in the Middle reach. Mass wasting frequencies for 1964 were 1 and 6 respectively. Each area maintained Vegetative Disturbance Levels

similar to their 1964 levels through 1983. By 1983, however, the frequency of mass wasting had jumped from 1 to 3 to 13 (Total=17) in the Bald Mt/Jim Creek subdrainage, and from 6 to 14 to 15 (Total=35) in the Middle reach of Canyon Creek. The rise in mass wasting frequencies reflects the differential response of each drainage area to forest practices and historical storm activity, and the cumulative effects of changing slope hydrology reflected in the lag time and distribution of mass wasting events over time.

The frequency of mass wasting provides useful trends when compared to harvest histories, but can be misleading. Vegetative Disturbance Levels in the Whistler Creek subdrainage, for instance, hover around 14% throughout the photo sequence. A single slide was initiated in 1989. This frequency could easily be considered acceptable risk in the planning of harvest activities. The single mass wasting event, however, ran the entire length of the subdrainage and into the main Canyon Creek channel. This mass wasting event was the result of heavily logged riparian areas in the lower drainage, and catastrophic storms in 1989. Relating mass wasting volumetric data to the physical characteristics of each subdrainage is clearly an important aspect in assessing the possible effects of managed activities.

Considering the high Vegetative Disturbance Levels for all but the Upper Creek, and the amount of mass wasting in the subdrainages, a Vegetative Disturbance Level percentage of 12% developed for the overall physiography of the North Cascades is called into question. It is likely that factors in the subdrainages of Canyon Creek necessitate a lower threshold percentage to maintain stability, and that Vegetative Disturbance Levels will have to be calculated to reflect smaller scale areas, like subdrainages (where impacts have tended to be concentrated) to assess long term project effects. It must be noted that in the upper creek, where Vegetative Disturbance Levels were maintained well below 12%, 14 mass wasting events were initiated between 1964 and 1983. Whether this is acceptable damage to watershed resources or not is a management decision, and the 12% threshold level alone is of little help in projecting long term cumulative effects.

Along with changes in the frequency of mass wasting, Harr (1986) and Nichols (1991) cite changes in channel morphology as a prerequisite for understanding the response of watersheds to managed activities. Channel morphology is the result of numerous complex factors including sediment stored on slopes and in channel reaches, storm activity, and the scale of human impact along the channel. Our inability to separate out these factors in this study, and the small number of sampled cross sections, makes conclusions about changing channel widths tentative and in need of empirical demonstration.

Five cross sections of Canyon Creek were measured across the photo years in an attempt to document changes in channel width over time for correlating with Vegetative Disturbance Levels, historical storm activity, and mass wasting histories (Table 17). Cross section A was located on the alluvial fan near the confluence of Canyon Creek and the North Fork of the Nooksack, and was expected to show the greatest variation in channel width. Cross sections B, C, and D, were placed below the confluences of the major subdrainages with the main creek channel (Jim, Kidney, and Whistler Creeks) to reflect flow changes in those

subdrainages, the effects of sediment stored in the main channel as a result of subdrainage peak flows, and to provide a representative sample of the main creek channel.

Cross section E was located above the upper bridge in the upper creek basin where the channel has incised through glacial-lacustrine sediments. No harvest activities have occurred on the slopes above cross section E, so it was hoped that changes in channel morphology at this cross section could be compared to pre-impact changes in channel morphology, since there are only two photo years (1940 and 1947) that provide information on background or natural changes in channel morphology prior to harvest activities. Storm intensity is likely less in the upper basin, the result of friction between storms and landforms in the lower drainage, widening of the valley in the upper basin, and backing up of storms against the mountains in the headwaters of the basin (and an increase in storm intervals above 3000ft). There are also more unforested areas in the upper basin, areas conditioned to storm impacts. Due to common problems in making equivalent measurements at significantly different photo scales, the resulting widths are not reliable as absolute numbers, and should be taken as ordinal measures for greater than or less than comparisons of channel widths.

Cross sections C-E show only minor or local fluctuations from the 1940 photo year through the 1983 photo year; in fact, the Kidney Creek and Upper Bridge cross sections (C and E) continue that trend throughout the photo sequence. One conclusion is that the channel above Kidney Creek is relatively stable, and that the minor fluctuations in channel width are the result of activity in the subdrainages, and the accumulation and flushing of sediment from upstream. It is also possible that sediment has been stored in the main channel that is not reflected in changing widths. Stored sediment has a lag time similar to that used to describe the difference between harvest years and slide initiation years. In the Whistler Creek subdrainage, for instance, the single slide event was initiated in 1979. In the 1983 photo, the channel width at the cross section associated with Whistler Creek (D) was narrower than either of the pre-impact photo years (1940 and 1947). By the 1991 photo year, however, channel width at that cross section had more than doubled, the result of a large storm in 1989, and possibly the flushing of stored sediment.

Likewise, of the 8 mass wasting events in the Kidney Creek subdrainage 6 were initiated between the 1964 and 1972 photo years. Differences in channel width after 1972 at the Kidney Creek cross section (C) do not differ significantly from fluctuations earlier than the dates of slide initiation, even at the 1991 photo year that post dates major flooding in Canyon Creek in 1989-90 (channel widths at cross section C appear to be trimodally distributed). It is possible that the cross section below the confluence of Kidney Creek does not adequately represent changes in channel width, or sediment from mass wasting in the subdrainage has not yet entered the stream system, and remains perched on side slopes.

Cross sections A and B at the alluvial fan and below the confluence of Jim Creek respectively show the greatest variation in channel width over time. Only the cross section at Jim Creek has a width in 1940 greater than the other cross sections, or for most of the subsequent years at cross section B. The

large channel width in 1940 (84m) suggests that there is a large natural variation in channel widths, variation not seen in our data due to the small number of photos pre-dating large scale human impacts in the watershed. The trend at cross section B from 1940 through 1972 is one of diminishing widths, and may represent revegetation and stabilizing of the channel. Cross section B is also in the area impacted by the large active trans-rotational Jim Creek slide (Ballerini, 1993). It is possible that the large channel width in 1940 is the result of undetected slide movement before 1940 (there is erosion of the toe slope noted in all the aerial photo years). It is not until the 1983 photo that channel width at cross section B breaks the trend of diminishing widths. The 1983 channel width at cross section B is nearly 6 times the width in 1972, and may represent the lag time between earlier slide movement and the flushing of sediment downstream after storms in 1981, or, as is likely the case, may represent continued movement and deposition of this slowly moving slide as it responds to storm activity. It is noteworthy that the channel moved laterally while retaining its original channel after storms in 1984.

The alluvial fan at the confluence of Canyon Creek with the North Fork Nooksack is the area of greatest deposition from peak flows in the main channel. Excepting the 1991 photo, channel widths at cross section A are unimodally distributed, with the peak at the 1956 photo year followed by a period of stabilization and revegetation through 1979. The large increase in channel width between 1947 and 1956 may be due in part to a fire and subsequent logging of private land in the lower drainage in the early 1950s. The channel width in 1991 at cross section A jumps from 24m in 1979 to 108m, reflecting massive flooding in the Canyon Creek watershed in 1989-90.

Due to the floods in 1989-90, we would expect channel widening in the majority of the drainage in the 1991 photo, and such is the case. Only the upper bridge cross section appears to be unaffected. It is interesting to note that in 1972, the photo year with the greatest number of initiated slides, channel widths at all the cross sections save the alluvial fan are relatively stable. Even the alluvial fan cross section in 1972 is in the process of stabilizing from an earlier peak width. This supports the notion of a lag time between slide initiation, sediment storage, and eventual flushing of the hydrologic system.

#### Discussion: Predicting Mass Wasting

For managers who are required to plan projects that sustain watershed and ecosystem equilibrium, the ability to predict the probability of mass wasting in a resource area is of primary importance. This discussion is intended for those charged with this task who are unfamiliar with the construction and use of predictive or risk assessment models, or with sampling problems in data collection.

The creation and implementation of risk assessment models has gained in popularity as the need for greater and greater accuracy in prediction has increased (and as time and budgets decrease). Models are simplifications of the world, as road or soil maps simplify what they represent on the ground.

They are created for specific purposes using specific data, and cannot be generalized beyond that purpose. A road map cannot be used for determining soil type locations, nor is a road map of the state very useful for finding your way around a big city. Unfortunately, there is a tendency to use models simplistically and uncritically, and beyond the limits of the data used in their construction (Harr, 1986).

Consider what is involved in modeling mass wasting potential across a landscape. Mass wasting in a given location, and the lag time between road-building or clearcutting and the initial mass wasting event, is caused by changes in slope hydrology, which, in turn, change the structural relationship between soil, sediment, and bedrock. Changes in slope hydrology are related to five primary factors: 1) the extent of, and time since, vegetative disturbance or reduction of the forest canopy closure around and above the slide location; 2) the extent, elapsed time, and type of road construction; 3) the number of activities stacked on a slope i.e. a harvest unit, a road through the harvest unit, and a harvest unit above; 4) the season; amount, duration, and intensity of storm activity; and 5) the structure and mechanics of the soil, sediment, and bedrock or geological matrix within which mass wasting occurs. Sediment in this context refers to unconsolidated materials without evidence of horizonization; they may be transported as with glacial outwash, or weathered in place from parent rock. The importance of distinguishing sediment from soil is that the soil matrix contains root systems, and may respond differently to concentrated water flows.

The five factors that contribute to changes in slope hydrology contain a wide range of required variables that describe the numerous complex relationships involved in the initiation of mass wasting. It is tempting to reduce the data collection requirements of these variables to a small set of key variables that would save time and money without significantly decreasing the information obtained. Numerous mass wasting models attempt to do this by relying on agronomic soil data (or other surface indicators) as surrogates for all the structural relationships between soil, sediment, and geology. Models do get simplified with use over time as certain relationships between variables remain steady, thereby reducing data collection time and costs. However, to reduce the number of variables in a model without first demonstrating that no important links will be overlooked is scientifically untenable, and can be disastrous to management decision making.

It is also tempting to reduce the number of data collection points without demonstrating that all the required information will be obtained. As a model, for instance, the Soil Resource Inventory (Snyder and Wade, 1970) was created for large scale watershed assessment, and data was collected in a widely dispersed manner for that scale. Unfortunately, the SRI has often been inappropriately used for smaller scale, project level assessments (where it is possible that none of the data collection locations fell within the proposed project area). It is appropriate to increase scale without increasing the number of data collection points (or conversely reduce the number of points in the original area) if project managers are willing to accept less accuracy in predictions, or are willing to accept more mass wasting in sub-basins. This is a critical consideration for project managers: before any models are utilized,

or any data is collected, managers must decide what level of mass wasting is acceptable within subdrainages. This decision drives all other considerations i.e. which model to use, or what Vegetative Disturbance Levels is acceptable.

Our ability to predict mass wasting in a watershed, or any long term effects of project activities then, is based in part on the type of data collected, the scale at which data is sampled or collected, and the scale to which generalizations from the data will be made. The smaller the information base (the fewer the number of sample locations), the less representative any data is of our specific project area, and the more we need to generalize in the planning process. The greater our generalizations, the less accurate our predictions. The fewer the number of sampled variables, the more we have to assume we are measuring important relationships, and the less able we are to specify which variables are responsible for the initiation of mass wasting. Soil Unit numbers in the SRI, for instance, are the result of collapsing three important variables into a single number. We have separated out the geomorphic origin of the soil/sediment, the slope percent, and the grain size distribution or soil texture. In future studies it is likely we would also collect data on the erosional and depositional regimes of different soils/sediments. Information on depositional regimes details the amount of energy needed to transport soil/sediment to its present location, thereby giving us an idea of the energy required to mobilize it in a mass wasting event.

How much data on a particular variable should be collected for accurate decision-making is ultimately a sampling and statistical question. A useful maxim is that data should be collected until redundancy is achieved, that is until no new significant information is forthcoming with continued sampling. When sampled data becomes redundant, information has been collected over the range of whatever attribute or variable is being measured, and the accuracy of predictive models is maximized. In practical terms, it is easier to collect too much information than too little, since data can be collapsed into larger units in the analysis phase. The reverse is not possible, and often leads to time consuming and expensive re-collection of data, or, as is more often the case, unwarranted conclusions based on insufficient data.

Thus far we have only considered the limitations of risk assessment models in terms of the kinds and scale of data used in their construction. To document the critical relationships between physical variables requires data collection on a wide range of variables. To date, we have only a general understanding of how physical variables like soil and bedrock type, elevation, aspect, slope angle, soil saturation and permeability levels, and other variables that behave relatively constantly, are related. Researchers are involved in the early stages of describing and understanding those variables thought to be responsible for past mass wasting events, and in developing methods and techniques for quantifying those factors. This has created an undue reliance on surface indicators like soil type or plant associations in landscape scale predictive models of mass wasting.

Unfortunately, surface indicators do not provide sufficient information on  
1) the geomorphic processes responsible for changes in both landforms and slope hydrology (those erosional and depositional regimes, for instance, responsible

for the infilling of hollows), and 2) those geologic structures (faulting, fracturing, and glacial abrading) responsible for the creation of hollows, and the concentration of water that leads to mass wasting. This is because surface indicators are only the matrix within which failures occur; they often mask important subsurface characteristics involved in the initiation of mass wasting, leaving no readily observable topographic expression. Combinations of field survey and remote sensing, and the mapping of geologic structures, soil types, slope angles, and vegetation composition, for instance, can be used to document the relationship between bedrock and soil/sediment structure, and how those affect slope hydrology in specific project areas.

The more we understand which physical variables are related at mass wasting sites (even if we do not know how or why they are related), the more accurate and site specific our predictions can be. After a number of watersheds have been inventoried using the general kinds of data utilized in the construction of this report it is likely that we will have a good understanding of which variables are important in determining the probability of mass wasting in watersheds with similar physiographies. This is the critical element for project managers. It is one thing, however, to predict that it will rain on the west side of the Cascades on a given day in November, and another to make the same prediction for the street where you live. Likewise, it is possible with great accuracy to predict that there will be mass wasting events in a watershed with certain soils on specific bedrock types and structures, and another to specify where in a particular soil unit or in what year a mass wasting event will occur (although field surveys can greatly improve the specification of potential mass wasting sites).

This is because some things, especially historical variables like the weather (or human behavior, or seismic activity) are said to behave stochastically. The behavior of some variables cannot be predicted with much precision because the ways they work is not well known. At other times the prediction of specific events is limited simply because of the sheer number of variables involved in the prediction and consequently the large number of possible outcomes (even if the variables are fully understood). Both aspects are involved in the prediction of mass wasting. This means that while it may be possible to specify in great detail the numerous parameters involved in the behavior of the weather, things like air temperature, wind speed and direction, relative humidity, and topography, it is not possible to accurately predict within those parameters the peak magnitude of the winter storms, the amount of snow pack, the saturation of soils, or any other weather-related variable that will affect a given drainage in a given year.

People who live in flood-prone areas are used to coping with the uncertainty of these kinds of predictions. Floods the magnitude of a 100-year flood may occur every 100 years, or for three (or more) consecutive years, even though they are most likely to occur every 100 years. That is why the prediction of stochastic variables is stated in terms of probabilities, and relies on constructing the history of past events in the creation of a database for use in modeling possible future events. Such predictions are based in a science that tells us what happens, not why they happen. Consequently, any unforeseen event, like a 150-year flood (or any interval beyond which we have

historical data), can affect the utility of the entire model, due to incompleteness and inaccuracies in the data used in its construction. This is problematic since this is information critical to the prediction of mass wasting.

The stochastic behavior of the weather is not the only problem in the creation of a historic database for use in predicting mass wasting potentials. Systematic weather information has been collected in this region for only 100 years. While some weather cycles, like El Nino, have a return interval of a few years, other cycles are measured in decades or millenia, and many other cycles are unknown. Weather cycles can also change rapidly. A database of only 100 years does not provide much information about the natural background of storm activity, or where in which weather cycle we sit. In attempting to plan for future impacts, this is critical information.

Further, storms in the North Cascades tend to be highly localized by drainage, especially in areas where weather patterns are strongly influenced by the proximity of Mt. Baker. For the purposes of this study it was assumed that peak water flow data from the gaging station on the North Fork Nooksack River (some miles upstream from the confluence of Canyon Creek) was directly related and comparable to actual storm activity from Canyon Creek. It functioned as a useful and inexpensive surrogate for explaining past project impacts. For predicting future impacts, or for comparing different watersheds, however, it is likely we would want to demonstrate the accuracy of this assumption. Storm tracking radar can be used to measure wind directions, precipitation amounts, and the duration of storm activities within drainages, and can be used to monitor storm activity over time for the creation of a long term historical database. Such remote sensing equipment cannot, however, provide information on differential storm intensity across a drainage, and other avenues must be considered to obtain that information. Considering the distribution of mass wasting locations in the Canyon Creek drainage, this may be critical information.

Even when we fully understand the relationships between the variables responsible for mass wasting, the large number, and the highly stochastic weather-related variable will limit our predictions about mass wasting to probability statements. The accuracy of predicting a mass wasting event for a specific parcel of land will always be well below one hundred percent, the accuracy increasing as the scale of land increases (much as weather forecasts are more accurate the larger the area under consideration). This means that our ability to accurately predict impacts to a watershed will be greater than our ability to predict impacts to a specific harvest unit.

This is due, in part, to the limited focus of current mass wasting inventories on how variables are related at places where mass wasting has occurred. Such historical inventories are critical in providing the foundation for accurate risk assessment by isolating variables and suggesting correlations and trends worthy of further study. They have done little, however, to increase our ability to explain why different variables combine to initiate mass wasting events, or which variables are correlated with each other, and which are secondarily correlated with some other causal factor. Consequently, the

validity of our explanations will remain untested until we also examine the relationship between variables in areas without mass wasting events. Only then will we have the background information to which variables from mass wasting sites can be compared.

The data from two mass wasting inventories conducted on the Mt. Baker District, for instance, and the conclusions from similar studies on the west side of the Cascades from northern California and Oregon, suggest that there is a relationship between soil type and changing slope hydrology (caused by storm activity) in the initiation of mass wasting events. We know the soil mechanics involved in mass wasting in terms of shear stress and changes in pore pressure, for instance, but the amount of water concentration, or increases in water delivery to specific sites are unknown. As a result, we might construct a risk assessment map based on soil types that would eliminate large areas from managed activities on the basis of certain unstable soil types. If, in our analysis of watershed areas without a history of mass wasting, we find many areas with those unstable soil types and no history of mass wasting, we can begin to conclude that slope hydrology is of prime importance. Our risk assessment map based on soil types then would have unnecessarily precluded large areas as potential project areas. The same map based on slope hydrology might look very different.

There is nothing simple about risk assessment; it is more than developing a map with zones of different risk levels outlined over which acceptable percentages of disturbance across the zones are plotted. Considering the relationship between mass wasting and fish spawning, for instance, and the uncertainty in predicting mass wasting events, what is an acceptable risk in such an assessment? That is a preliminary decision project managers must face, and considering the possible consequences, it is a decision that should be made explicitly and early in the planning process. To return to the flood magnitude analogy, is it an acceptable risk to plan for a 100-year flood, or are the potential impacts to ecosystems of great enough severity that project planning should account for 25 or 50-year floods? Or, put another way, is it acceptable to be wrong half the time, or are the consequences such that project managers are only willing to be wrong 5% of the time? In a real life situation, it is interesting to note that in the 1993 California earthquake, the freeways determined a low probability for failure, and consequently unimproved since the 1971 quake, were those that collapsed.

Once a decision has been made as to an acceptable level of risk, project planners need to make certain the models they use were developed to be sufficient at that level of risk. Risk assessment is based on these kinds of decisions, decisions that are made explicitly and early in a planning process that includes the cumulative impacts of projects over time and across space. This begs a certain conservatism in decision-making, considering the results of past mass wasting on both watersheds and areas far downstream.

### Summary:

Prior to large scale human impacts, the Canyon Creek watershed was a relatively stable drainage as recently as 1940, the first photo record we have of the basin. Stability means that the drainage system was able to handle storm-related sedimentation (as seen in the variation in channel cross sections through time) without a significant increase in the number of mass wasting events.

This study has attempted to demonstrate the causes of mass wasting in the Canyon Creek subdrainage by looking for commonalities in the physical characteristics of the mass wasting sites, and by comparing the timing and locations of mass wasting events to human impacts and storm activity in the drainage.

The relationship of mass wasting to aspect is the only physical characteristic with obvious patterning, and is explained by analyzing the direction and season of storm activity in the basin, and the differential impact of precipitation on slopes up the drainage. The timing of mass wasting in the drainage appears to be related more to the timing of human impacts in the watershed, since precipitation patterns (the average amount and season of storm activity, and cycles of peak storms) are consistent across time. Only the level of human impact in the drainage has changed significantly in the last fifty years. At the subdrainage scale, Vegetative Disturbance Levels are well above the threshold for maintaining watershed stability. Considering the level of mass wasting and sediment deposition in subdrainages, the risk of impact by storm activity was greater than anticipated, for a longer period of time. Cyclical large scale storms may have a role in triggering mass wasting on marginally stable slopes, but correlating specific past storm events to the initiation of specific mass wasting events is not possible using aerial photos. The creation of an ongoing historical database, and a refinement of the analyzed physical characteristics i.e. geologic structure will help resolve this situation.

## Appendix 1: Discussion of Statistical Calculations

The expected discharge used in the chi-square calculation assumed that the average amount of water discharged was the same for every year within each photo year unit (that notable cycles in the amount of precipitation over the years is absent). If all our actual averages were the same as those expected, then the data is evenly and non-randomly distributed, and there are no particular cycles in the discharge data present, even though there appear to be cycles of high peak storm activity and cycles of low peak storm activity. If the results of the statistical tests indicate the data is, indeed, evenly distributed, the apparent cycles in the data will have been discounted, since our assumption of similarity in the average amount of peak discharge every year will have been met.

Conversely, if the actual averages are too far above or below what we expected i.e. the data is randomly and unevenly distributed, then we could conclude that there is no pattern. If a different pattern does exist in the data, other ways must be used to characterize the cycles.

The average or mean peak discharges for the photo year units is as follows (the chi-square value for each is included in parentheses):

1940-47= 5220cfs (1.48); 1948-56= 5034cfs (1.89); 1957-64= 5180cfs (0.43);  
1965-72= 5045cfs (1.47); 1973-79= 5011cfs (2.87); 1980-83= 5050cfs (1.34);  
1984-91= 5352cfs (9.39).

In statistical terms, the chi-square test assesses the probability of obtaining numbers as different from those expected if the data within the photo year units is evenly distributed. If all the above chi-square numbers are included, the sum is 18.87. By comparing that number to those in a chi-square table of probabilities, we see that the probability of obtaining that chi-square value as similar as those expected is between 0.5% and 0.1% ( $0.005 < P < 0.001$ ). Considering that 5% (0.05) is the commonly accepted level of significance (the level of confidence used to either accept or reject the assumption that our actual averages will match our expected average discharge), we can conclude that the average peak discharge data is randomly and unevenly distributed, since we could only expect to obtain averages that match our expected averages in a similar way between 1 and 5 times out of a thousand (and therefore our sample does not reflect the overall population of discharge data). Our initial conclusion then is that there are cycles in the discharge data that are different than our assumption that each year within each photo year unit would have similar amounts of discharge.

Upon examination of the chi-square values, it can be seen that one of the apparent cycles of high peak storm activity (the photo year unit encompassed between 1984 and 1991, when severe floods caused tremendous damage to the entire Nooksack drainage) has a comparatively high chi-square value. If we eliminate this large chi-square value, the chi-square sum drops to 9.48. The chances of obtaining the remaining chi-square values by chance alone is between 5% and 10% ( $0.10 > P > 0.05$ ). In other words, we are still 90% to 95% certain that there is a non-random pattern in the distribution (cycles), although we

have eliminated one of the largest presumed cycles of storm activity. We are also less confident that our data is not random, since our probability has shifted from 1-5 times out of a thousand to 5-10 times out of 100 that we would get a similar match of average discharges to our expected average discharges if we were to repeat the study.

Our second statistical question asks in which photo year unit is the data non-random? Our first suspicion is that the last photo year (1984-1991) may be contributing non-randomness to the data, since the chi-square sum is almost halved when that photo year unit chi-square value is removed.

Since the chi-square test is very sensitive to extreme measures (very high or very low peak discharge levels), an additional test, the Student's t-test was utilized to determine whether there is a statistically significant difference between the average peak discharges between pairs of photo year units. This test includes all the variation within the peak discharge data for a given photo year unit for comparison with other photo year units, which minimizes the effects of extremes in the data. It is possible, for instance, that the cause of the high chi-square value for the 1984-1991 photo year unit (more than three times the chi-square value of any of the others) is the number, and comparatively high peak storm discharge rates of storms during that time period. These large storms may not reflect the overall discharge rate for those years. This is a different kind of test than the chi-square test where all the averages were compared; the t-test compares the averages and variation between two photo year units in terms of their equivalence (their similarity or dissimilarity).

Prior to running the t-test, the variances between each of the twenty-one pairs of photo year units were tested using the F-distribution to ascertain whether variances should be pooled for the subsequent t-test. Five of the twenty-one required pooling for the t-test.

As with a chi-square test, a statistic is calculated from the data (the t-statistic), and compared to critical values in a table. Once again, the 0.05 level of significance is used as the cut-off for rejecting the hypothesis that the pairs of averages being compared are equal (in favor of the alternative that they are not equal). The 0.05 (5%) level indicates that 5% of the time we are willing to admit that we might accept the hypothesis that the units being compared are equal, when they are, in fact, unequal and dissimilar (called a Type I Error).

For the twenty-one paired photo year unit t-tests, the t-scores ranged from a negative 0.31 (for the 1956 and 1964 photo year unit pairs) to 0.65 (for the 1947/1972 pairing). Critical values of t were all between (negative and positive) 2.0 and 2.1 at the 0.05 level of significance. Since none of the t-scores was greater than the associated negative or positive critical value of t we cannot reject our assumption/hypothesis that all the compared pairs of photo years are equal. This means that no particular time encompassed by the photo year units is wetter or drier than any other. This also means that apparently high average peak discharge for the 1984-1991 photo year unit, with its elevated chi-square value, is not significantly different than any other photo year unit. The high chi-square value for that photo year unit then is the result of the extremes in specific storm events, and not the result of overall high peak discharge.

Table 1: Mass Wasting Type by Site Condition

	Natural	Clearcut	Road Fill	Road Cut	Landing	Total
Debris Slide (DS)	2	17	8	1	1	29
Debris Flow (DF)	0	21	5	0	3	29
Debris Avalanche (DA)	1	7	3	0	0	11
Debris Torrent (DT)	1	12	3	0	4	21
Trans-Rotational (TR)	0	4	0	0	0	4
Scoured Channel (SC)	1	4	0	0	0	5
TOTAL	5	65	19	1	8	98

Table 2: Mass Wasting Type by Subdrainage

	Bald Mt	Jim Cr	Kidney Cr	Whistler Cr	Lower	Mid	Upper
DS	4	6	3	0	8	6	1
DF	1	2	3	0	2	16	5
DA	0	0	2	1	2	6	0
DT	2	1	0	0	1	11	6
TR	1	2	0	0	0	1	0
SC	0	0	0	0	0	1	3
TOTAL	9	11	8	1	13	42	15

Table 3: Mass Wasting Type by Geological Unit\*

	uPcs	PMel	Qs	pDy	uPcv	TS	JKn
Debris Slide	7	9	0	2	0	11	0
Debris Flow	8	6	2	0	11	2	0
Debris Avalanche	5	2	0	0	2	2	0
Debris Torrent	9	3	1	2	4	2	0
Trans-rotational	0	1	1	0	0	1	0
Scoured Channel	0	0	1	0	1	0	2
TOTAL	29	21	5	4	18	18	2

\*uPcs: sedimentary and slightly metamorphosed sedimentary rocks of the Chilliwack Group (the largest rock unit in the drainage, especially both sides of the upper canyon).

PMel: metamorphic chert, basalt, and volcanic sandstone of the Elbow Lake Formation (Bald Mt. subdrainage and the upper portion of the lower canyon).

Qs: sedimentary deposits (mid and upper creek bottoms).

pDy: highly metamorphosed rocks of the Yellow Aster Complex (mid-canyon and Kidney and Jim Creeks).

uPcv: slightly metamorphosed volcanic rocks (Church and Bearpaw Mts., and along fault zone, mid-canyon).

Ts: sedimentary rocks, mostly from the Chukanut Formation (Bald Mt., and both sides of the lower canyon; bounded by major faults).

JKn: volcanic sandstone, siltstone, and argillite from the Nooksack Group (small rock unit in the headwaters).\*\*

\*\* from the Geological Map of the Northwest Cascades, Washington, 1986

Table 4: Mass Wasting Type by Slope Position

	Lower	Mid	Upper
Debris Slide	14	10	4
Debris Flow	27	2	0
Debris Avalanche	8	2	1
Debris Torrent	19	2	0
Trans-rotational	3	0	1
Scoured Channel	3	1	0
Stream Slump	<u>1</u>	<u>0</u>	<u>0</u>
TOTAL	74	17	6

Table 5: Mass Wasting Type by Aspect

	N	NE	E	SE	S	SW	W	NW
Debris Slide	3	2	0	11	2	3	2	5
Debris Flow	1	0	0	8	7	6	3	4
Debris Avalanche	0	1	0	5	1	2	1	1
Debris Torrent	2	2	0	4	8	1	1	4
Trans-rotational	0	0	0	1	0	0	0	3
Scoured Channel	0	0	0	0	0	2	1	0
Stream Slump	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>1</u>
TOTAL	6	5	0	29	18	14	8	18

Table 6: Mass Wasting Frequencies by Aspect and Subdrainage

	N	NE	E	SE	S	SW	W	NW
Bald Mt.	0	1	0	7	1	0	0	0
Church/Jim Cr.	3	1	0	0	0	2	1	4
Kidney Cr.	0	1	0	0	0	7	0	0
Lower	0	2	0	8	0	0	0	3
Middle	2	0	0	15	7	3	4	11
Upper	1	0	0	0	10	2	2	0
Whistler Cr.	0	0	0	0	0	0	1	0
TOTAL	6	5	0	30	18	14	8	18

Table 7: Mass Wasting Type by Soil Unit

Soil Unit	DS	DF	DA	DT	TR	SC	TOTAL	Stability*	Grouped Units and Totals
19	0	0	0	0	0	1	1	III-IV	
29	0	3	1	1	0	1	6	III-IV	
36	0	0	0	1	0	1	2	I-II	transported glacial tills (N=47)
37	3	6	4	10	0	1	31	II	
38	0	3	2	2	0	0	7	III-IV	
51	4	0	2	0	0	0	6	II	
54	5	2	0	1	0	0	8	II-III	nonmarine sedimentary rocks (N=25)
56	5	1	1	1	2	0	11	IV-V	
617	0	3	1	1	0	0	5	II	metasedimentary rocks (N=15)
628	1	2	0	3	0	0	10	II-III	
78	0	1	0	0	0	0	1	III-IV	schistose rocks (N=1)
91	1	0	0	0	1	0	2	II	
92	0	1	0	0	0	0	1	II-III	extrusive igneous rocks (N=6)
917	1	0	0	1	0	0	3	II-III	

\*Stability Index from the Soil Resource Inventory, Mt. Baker NF (1970):  
I is the most stable, and V the least.

Table 8: Mass Wasting Frequencies by Slope Per Cent and Aspect, and by Grouped Soil Units

Aspect	Slope Per Cent							
	5-15	16-25	26-35	36-45	46-55	56-65	66-75	76-90
N	0	0	0	2	2	0	0	2
NE	0	1	0	0	1	0	3	0
E	0	0	0	0	0	0	0	0
SE	0	0	1	5	4	9	2	5
S	0	1	1	6	2	3	3	0
SW	0	0	2	6	6	0	0	0
W	0	0	1	3	1	2	0	0
NW	0	2	0	6	4	1	1	2
TOTAL	0	4	5	28	21	15	9	9
Grouped Soil Units								
19-38	0	1	4	17	14	10	0	0
51-56	0	3	1	4	2	2	6	9
617/628	0	0	0	4	4	3	3	0
78	0	0	0	1	0	0	0	0
92/917	0	0	0	2	2	0	0	0

Table 9: The Geologic Structure of Failure Locations by Subdrainage

	HF*	TF	DS	SP	RU	SZ	C	IN
Lower Creek	00	00	05	08	00	00	00	00
Bald Mt/ Jim Cr.	14	00	00	04	00	02	00	00
Kidney Creek	00	03	00	04	00	00	01	00
Middle Creek	04	10	00	08	09	05	00	06
Upper Creek	03	00	02	01	01	01	06	01
Whistler Creek	00	00	00	01	00	00	00	00
Totals	21	13	07	26	10	08	07	07
Mass Wasting Type								
Debris Flow	08	06	01	05	02	01	02	04
Debris Slide	05	01	04	15	01	02	00	00
Debris Avalanche	00	01	01	04	04	01	00	00
Debris Torrent	03	04	01	02	03	03	04	01
Trans-Rotational	03	00	00	00	00	01	00	00
Scoured Channel	01	00	00	01	00	00	01	01

\* HF: high angle fault; TF: thrust fault; DS: dipslope; SP: strike-dip;  
RU: rock unit contact; SZ: shear zone; C: cleavage; IN: indeterminant

Table 11: Vegetative Disturbance Levels for Falls Creek Subdrainage  
by Photo and Current Year (1993)

Year Cut	Harvested Acres	Adjusted Acres by Photo Years					
		1956	1964	1972	1983	1991	1993
1983	24	----	----	----	00	19	18
1962	52	----	48	38	23	13	10
1983	30	----	----	----	00	23	22
1964	49	----	00	38	25	15	12
1957	03	03	02	02	01	00	00
1965	21	----	20	17	11	07	06
1958	43	----	36	27	15	07	04
1966	42	----	39	35	23	15	13
1973	50	----	----	48	37	27	24
1966	21	----	20	17	12	07	06
1963	19	----	18	14	09	05	04
1983	03	----	----	----	00	02	02
1986	15	----	----	----	----	13	12
1973	77	----	----	73	56	41	37
TOTALS	449	03	39	308	212	194	171

Total Productive  
Forest= 1057acres

Vegetative Disturbance Level (%)	0.3	4	29	20	18	16
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Table 12: Vegetative Disturbance Levels Kidney Creek Subdrainages  
by Photo and Current Year (1993)

Year Cut	Harvested Acres	Adjusted Acres by Photo Year					
		1956	1964	1972	1983	1991	1993
1969	19	----	----	15	05	00	00
1959	38	----	32	25	14	07	05
1959	14	----	12	09	05	03	01
1980	22	----	----	----	20	15	14
1971	189	----	----	180	129	91	81
1963	14	----	13	11	06	04	03
1966	40	----	37	33	22	14	12
1963	48	----	46	36	23	13	10
1983	10	----	----	----	00	08	07
1963	19	----	18	14	09	05	04
1964	23	----	00	18	12	07	06
1972	11	----	----	00	08	06	05
1965	08	----	----	06	04	03	02
TOTALS	455	----	158	347	257	176	150
Vegetative Disturbance Level (%)		----	11	25	19	13	11
Mass Wasting Frequencies		----	----	6	2	----	----
Total Productive Forest=	1380acres						

Table 13: Vegetative Disturbance Levels for Bald Mt/Jim Creek Subdrainage  
by Photo and Current Year (1993)

Year Cut	Harvested Acres	Adjusted Acres by Photo Years					
		1956	1964	1972	1983	1991	1993
1953	87	70	35	00	00	00	00
1954	173	148	82	16	03	01	00
1957	21	----	17	13	07	03	02
1958	86	----	71	52	28	10	08
1959	216	----	153	122	19	09	07
1962	92	----	84	59	28	17	14
1963	14	----	13	07	00	00	00
1964	144	----	138	88	20	12	10
1965	09	----	----	05	00	00	00
1966	78	----	----	61	35	20	17
1967	01	----	----	01	00	00	00
1970	63	----	----	50	23	05	04
1972	04	----	----	04	03	02	01
1973	74	----	----	----	49	31	27
1976	46	----	----	----	32	17	14
1977	35	----	----	----	29	22	20
1978	41	----	----	----	31	18	14
1979	44	----	----	----	33	15	11
1982	35	----	----	----	32	18	14
1983	88	----	----	----	85	61	54

TOTALS	1351	218	593	478	457	261	217
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Vegetative Disturbance Level (%)	8	22	18	17	10	8
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Mass Wasting Frequencies (1940= 2)	1	1	3	13	1	0
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Total Productive  
Forest= 2706acres

Table 14: Vegetative Disturbance Levels for Middle Canyon Creek  
Subdrainage by Photo and Current Year (1993)

Year Cut	Harvested Acres	Adjusted Acres by Photo Years					
		1956	1964	1972	1983	1991	1993
1956	218	214	170	126	120	22	11
1957	143	----	114	86	43	19	11
1958	157	----	129	97	91	23	15
1959	39	----	28	14	02	01	00
1962	50	----	47	37	23	13	10
1963	78	----	73	51	23	13	11
1964	300	----	292	215	109	65	54
1965	317	----	----	221	88	50	42
1966	67	----	----	56	37	23	20
1969	05	----	----	04	03	02	01
1973	54	----	----	----	39	29	26
1974	129	----	----	----	97	71	65
1980	20	----	----	----	16	08	06
1982	41	----	----	----	37	21	16
1983	65	----	----	----	64	34	31
1985	05	----	----	----	----	04	04
1986	26	----	----	----	----	22	21
TOTALS 1714		214	853	907	792	420	344
Vegetative Disturbance Level (%)		12	50	52	46	24	20
Mass Wasting Frequencies (1940= 2)		1	6	14	15	2	0
Total Productive Forest= 1734acres							

Table 15: Vegetative Disturbance Levels for Upper Canyon Creek Subdrainage  
by Photo and Current Year (1993)

Year Cut	Harvested Acres	Adjusted Acres by Photo Years					
		1956	1964	1972	1983	1991	1993
1960	64	----	56	44	26	13	10
1962	306	----	285	223	138	77	61
1964	29	----	28	23	15	09	07
1965	111	----	-----	89	59	37	31
1966	49	----	-----	41	28	17	16
1967	32	----	-----	27	19	12	11
1968	81	----	-----	71	49	32	28
1973	64	----	-----	-----	47	34	31
1979	21	----	-----	-----	19	14	13
1980	15	----	-----	-----	14	11	10
1984	59	----	-----	-----	-----	47	44
1985	27	----	-----	-----	-----	22	21
1986	34	----	-----	-----	-----	30	27
TOTALS	892	----	369	518	414	355	310

Vegetative Disturbance Level (%)	----	8	11	9	7	6
--	------	---	----	---	---	---

Mass Wasting Frequencies	----	2	9	3	0	0
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Total Productive  
Forest= 4891acres

Table 16: Vegetative Disturbance Levels for Whistler Creek Subdrainage  
by Photo and Current Year (1993)

Year Cut	Harvested Acres	Adjusted Acres by Photo Years					
		1956	1964	1972	1983	1991	1993
1963	7	----	6	4	00	00	00
1964	60	----	58	40	15	09	08
1967	32	----	----	27	19	12	11
1968	74	----	----	65	44	30	30
1979	85	----	----	----	70	44	38
1985	21	----	----	----	----	17	16
1986	15	----	----	----	----	14	13
TOTALS	294	----	64	136	148	126	116
Vegetative Disturbance Level (%)		----	14	15	16	14	13
Mass Wasting Frequencies		----	0	0	1	0	0
Total Productive Forest=898acres							

Table 17: Changes in Channel Width at Five Cross-Sections of Canyon Creek  
(in meters)

	Photo Years:							Approximate Location
	1940	1947	1956	1964	1972/79	1983/86	1991	
A	42	56	80	----	48/24	----	108	alluvial fan (lower)
B	84	50	48	24	16	90	90	Jim Creek
C	21	14	16	24	16	22	24	Kidney Creek
D	21	28	16	12	16	15	36	Whistler Creek
E	21	14	16	12	16	15	12	upper bridge

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Table 18: Canyon Creek Mass Wasting Raw Data

Subdrainage	Num Slide Yr		Type	Length	Width	Depth	Rock Unit	Rock Struct	Soil	Sediment
UPPER	1	72	SC	900	10	3	JKN	C	19	1000
UPPER	2	72	SC	1320	10	3	UPCV	IN	37	200
UPPER	3	72	SC	1300	20	6	JKN	SP	36	3000
UPPER	4	72	DT	1815	100	6	UPCS	C	37	40300
UPPER	5	72	DT	2145	100	6	UPCS	C	37	10000
UPPER	6	72	DF	495	75	6	UPCS	C	37	
UPPER	7	72	DT	1650	100	6	UPCS	C	37	36700
UPPER	8	80	DF	990	30	3	UPCS	D	617	
UPPER	9	72	DT	2300	60	6	UPCS	C	37	
UPPER	10	61	DF	1075	75	10	UPCS	RU	37	38000
UPPER	11	64	DT	1155	30	10	UPCS	D	37	2600
WHISTLERCR	12	79	DA	330	100	10	UPCS	SP	617	
UPPER	13	73	DF	500	50	3	UPCS	HF	617	
UPPER	14	72	DT	1650	50	3	UPCS	HF	617	
UPPER	15	73	DF	800	50	3	UPCS	HF	617	500
MIDDLE	16	79	DF	500	75	10	UPCV	TF	38	1400
MIDDLE	17	72	DF	800	100	6	UPCV	TF	38	1800
MIDDLE	18	64	DF	600	100	10	UPCV	TF	628	7000
MIDDLE	19	64	DF	800	75	10	UPCV	RU	37	
MIDDLE	20	79	DT	1320	75	6	UPCS	SZ	37	22000
MIDDLE	21	79	DA	1650	75	6	UPCS	RU	37	
MIDDLE	22	83	DT	2640	100	6	UPCS	SP	37	17600
MIDDLE	23	72	DT	1320	50	6	UPCS	RU	37	4500
MIDDLE	24	72	DA	1320	75	10	UPCV	RU	38	3700
MIDDLE	25	79	DT	1800	50	6	UPCV	RU	38	2000
MIDDLE	26	83	DT	100	75	6	UPCV	RU	38	
MIDDLE	27	79	DT	1300	75	10	PDY	TF	37	3600
MIDDLE	28	83	DT	660	100	10	UPCV	TF	628	1200
MIDDLE	29	83	DT	700	100	3	UPCV	TF	628	7200
MIDDLE	30	83	DF	500	100	10	UPCV	TF	628	
MIDDLE	31	72	DS	1320	75	6	PDY	SP	37	2000
MIDDLE	32	71	DT	3960	200	15	PDY	TF	37	66000
MIDDLE	33	83	DA	1485	200	6	PMEL	SP	29	19800
MIDDLE	34	81	DT	1800	75	10	PMEL	SZ	628	36750
KIDNEYCREEK	35	71	DA	600	50	10	UPCS	SP	37	1200
KIDNEYCREEK	36	79	DF	2000	75	6	UPCS	C	37	30000
KIDNEYCREEK	37	79	DS	500	200	30	UPCS	SP	37	6000
KIDNEYCREEK	38	72	DS	500	75	10	UPCS	SP	917	14000
KIDNEYCREEK	39	72	DS	600	75	10	UPCS	SP	37	18000
KIDNEYCREEK	40	72	DF	400	75	10	UPCS	TF	37	7400
KIDNEYCREEK	41	72	DF	800	50	10	UPCV	TF	37	15000
KIDNEYCREEK	42	72	DA	1200	100	10	UPCV	TF	38	21000
MIDDLE	43	72	DA	1300	100	10	UPCS	RU	37	16000
MIDDLE	44	72	DA	600	300	6	UPCS	RU	37	5000
BALDMTNSET/R	45	72	DT	2000	50	6	QS	SZ	29	36000
BALDMTNSET/R	46	79	DF	1300	50	10	UPCV	HF	29	24000
MIDDLE	47	72	DS	2300	50	6	PMEL	SZ	628	3300
MIDDLE	48	79	DT	200	50	10	PMEL	IN	36	1000
MIDDLE	49	72	DF	500	50	10	UPCV	SP	38	27500
MIDDLE	50	72	DF	200	200	10	PMEL	SZ	56	14800
MIDDLE	51	79	DA	400	200	10	PMEL	SZ	56	5400

Table 18: Canyon Creek Mass Wasting Raw Data

Subdrainage	Num	Slide Yr	Type	Length	Width	Depth	Rock Unit	Rock Struct	Soil	Sediment
UPPER	52	72	DS	500	200	20	PMEL	SZ	56	8000
CH-JIM T/RS	53	80	DT	600	50	10	PMEL	HF	917	24000
CH-JIM T/RS	54	84	DS	500	75	10	TS	SP	54	
CH-JIM T/RS	55	84	DS	600	75	10	TS	SP	54	
CH-JIM T/RS	56	79	DS	800	50	6	TS	SP	54	
CH-JIM T/RS	57	79	DF	1000	30	6	UPCV	HF	92	6600
CH-JIM T/RS	60	85	DS	150	200	5	PMEL	HF	56	
CH-JIM T/RS	61	85	DS	150	200	5	PMEL	HF	56	
MIDDLE	62	83	DF	300	550	10	PMEL	HF	29	600
MIDDLE	63	64	DF	300	65	10	PMEL	HF	29	
LOWER	64	54	DS	1000	30	3	TS	DS	51	
LOWER	65	54	DS	100	750	10	TS	DS	51	3000
CH-JIM T/RS	66	54	TRS	1600	150	10	QS	HF	56	89000
LOWER	67	79	DF	1300	30	6	TS	SP	54	6300
LOWER	68	79	DF	1000	30	6	TS	SP	54	4700
LOWER	70	79	DT	3300	50	6	TS	SP	54	15000
BALDMTNSET/R	71	72	DT	1000	50	6	TS	HF	56	4400
LOWER	72	56	DS	1500	300	3	TS	SP	54	17000
LOWER	73	83	DA	2000	50	3	TS	SP	51	2200
LOWER	74	56	DA	1300	30	3	TS	DS	51	1000
BALDMTNSET/R	75	79	TRS	680	80	15	TS	SZ	56	30200
LOWER	76	64	DS	700	50	3	TS	SP	56	4000
LOWER	78	56	DS	800	50	3	TS	SP	56	2000
LOWER	79	56	DS	500	50	3	TS	SP	54	1500
LOWER	80	64	DS	500	30	3	TS	D	51	1000
LOWER	81	56	DS	600	50	3	TS	DS	51	1500
CH-JIM T/RS	101	40	TRS					HF		
MIDDLE	102	72	DF	630	78	6	UPCS	HF	37	
MIDDLE	105	91	DF			6	QS	IN	37	
MIDDLE	106	91	DF			6	UPCV	IN	37	
MIDDLE	109	72	DF	390	78	3	UPCV	IN	628	
MIDDLE	110	40	DS			3	PDY	TF	91	
MIDDLE	113	72	DF	235	78	6	QS	IN	78	
MIDDLE	114	72	SS	235	235	3	QS	IN	628	
MIDDLE	115	40	TRS				PMEL	HF	91	
CH-JIM T/RS	116	86	DF	390	78	3	PMEL	HF	917	
BALDMTNSET/R	118	40	SE				UPCS	HF		
CH-JIM T/RS	119	91	DS	390	78	6	PMEL	HF	56	
MIDDLE	120	64	DS	440	63	3	PMEL	RU	628	
MIDDLE	121	56	DS	160	80	6	UPCS	TF	37	
MIDDLE	122	72	DS	1020	80	6	PMEL	SP	37	
MIDDLE	123	86	DS	1000	80	6	PMEL	SP	37	
MIDDLE	124	64	DF	375	63	3	PMEL	SP	628	
MIDDLE	125	64	DF	440	250	6	PMEL	SP	29	
BALDMTNSET/R	130	86	DS	200	100	3	UPCS	HF		
BALDMTNSET/R	131	86	DS	250	50	3	UPCS	HF		
BALDMTNSET/R	132	86	DS	300	50	3	UPCS	HF		
WHISTLERCR	137	89	DT	6500	100	3	UPCS	RU		
BALDMTNSET/R	138	64	DS	440	63	6	PMEL	SP	37	